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ZONES OF PERICRATONIC SUBSIDENCES - PLATFORM STRUCTURES OF THE FIRST ORDER¹

by

Ye. V. Pavlovskiy

It is customary in Soviet tectonics to consider shields, blocks, synclises and anticlises as platform structures of the first order. Blocks are contrasted to shields as regions of prolonged submergence and prolonged sedimentation. The combination of synclises and anticlises, together with smaller structures (uplifts, depressions, flexures, arches, placanticlines, domes, folds, forms of salt tectonics), determines the structure of the platform cover within the blocks. No definite patterns whatsoever have been recognized, apparently, in the spatial and temporal distribution of both shields and blocks, or of synclises and anticlises.

Structures occurring in zones of contact between ancient platforms and their surrounding geosynclinal regions attract particular attention. It is considered that platforms are separated, as a rule, from the geosynclinal regions which enclose them by zones of marginal jointing — fractures with a deeply-laid foundation and with a prolonged development. Strictly speaking, however, the existence of these fractures is only demonstrable in those relatively rare places where the highly uplifted edge of an ancient platform immediately adjoins the geosynclinal region. The zone of contact between the northwestern edges of the Baltic shield of the Russian platform and Caledonian Scandinavia serves as a classic example of this kind of relationship.

The more general relationship of ancient platforms with the surrounding zones of folding is expressed quite differently. The outlying part of the platform is more or less strongly depressed, the longitudinal, marginal and transverse flexures being superimposed on the outer edge of the platform. Both are formed only during a specific historical stage in the development of the geosynclinal region adjoining the platform — only during the period of folding and orogenesis in this

region. In other words, the relatively short duration of the period is emphasized during which the longitudinal, marginal and transverse flexures are developed. One research worker (N.S. Shatskiy, followed by N.S. Zaytsev and others) proved the existence of ancient marginal flexures, choosing as an example the Angara-Lena and Berezov flexures on the southeastern edge of the Siberian platform.

According to their ideas, the marginal flexures of the Baykal folding are "completely analogous to the marginal flexures of later geologic epochs" ([1], p. 34). On the other hand, according to the opinion of N.S. Shatskiy, A.A. Bogdanov and A.L. Yanshin [6], the typical marginal flexures of the Caledonian orogeny are absent, these flexures appearing in strictly later stages of the development of the Earth's crust, in connection with the Hercynian, Mesozoic and Alpine movements. A still more distinct position on this question is taken by Yu.M. Pushcharovskiy [15, 16], who terms the marginal flexures "narrow, deep, synclinal structures extending for several hundred and sometimes for more than a thousand kilometers, and elongated along the fronts of folded zones". . . . "these structures had a brief period of development," arising and being developed during the epoch of the closing and general uplift of the geosynclinal system. According to the opinion of this research worker, the longitudinal and marginal flexures were only formed during the Hercynian, Mesozoic and especially the Alpine periods of folding. The conclusion is hence drawn that the relatively older, Caledonian, geosynclinal process had a comparatively feeble influence on the margins of the platforms. Later, during the process of the Hercynian and Mesozoic folding, this influence was exceptionally strong.

In the light of these ideas which have a bearing on N.S. Shatskiy's theory of the phased development of the geosynclinal process, it is incompetent, and also not logical, to include the Angara-Lena flexure of the Siberian platform and other analogous structures of ancient

¹Zony perikratonnykh opuskaniiy — platformennyye struktury pervogo poryadka.

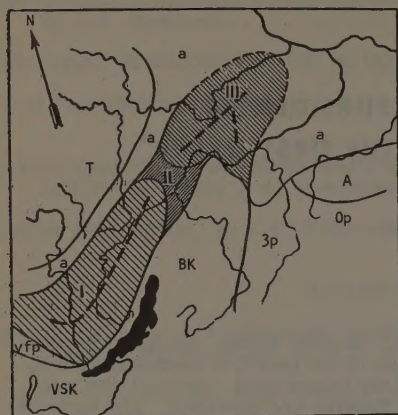


FIGURE 1. Angara-Lena zone of pericraton subsidences in the Paleozoic (schematic).

I -- Upper Lena depression; II -- Peleduy transverse uplift; III -- Nyuyoy-Vilyuy depression;
a -- sides of the shields and of the anticlises; T -- Tungus syncline; BK -- zone of the Baykal Caledonids; VSK -- Caledonid zone of eastern Sayan; 3p, Op, -- zone of early Proterozooids; vfp -- projection of the fundamental platform; A -- Aldan shield.

Broken line -- axis of the zone of subsidence.

platforms in the category of marginal flexures.

The Angara-Lena flexure and other similar structures of ancient platforms cannot be regarded as marginal flexures for the very reason that the development of this flexure was by no means of a short duration. On the contrary, as the facts show, the process of formation of this enormous structure on the southern edge of the Siberian platform was unusually prolonged; it did not correspond in time to any one "epoch of folding," but enveloped a number of geologic periods and even exceeded, apparently, the limits of the Paleozoic era.

The Angara-Lena flexure, with a width up to 400 kilometers, extends from southwest to northeast, from the foothills of eastern Sayan to the region of the middle reaches of the Vilyuy River, i.e., for approximately 1,500 kilometers. To the southeast, the flexure is bounded by the marginal uplifts of the Sayano-Baykal Caledonids, and on the northwest by the anticlises of the eastern side of the Tungus flexure [1, 6, 7, 17, 18]. It is also known that the structure of the Angara-Lena flexure is rather complex. There are two

depressions, the Upper Lena and the Nyuyoy-Vilyuy, separated by the Peleduy transverse uplift. This uplifted zone is chiefly formed of folded and crumpled rocks of the lower division of the Cambrian (Fig. 1).

The enormous Upper Lena depression is situated southwest of the Peleduy uplift, extending as far as the foothills of eastern Sayan. It is composed of deposits of the Lower (about 3,000 meters), Middle (tens of meters) and Upper Cambrian (300 to 400 meters and more), the Ordovician (550 to 650 meters), and in places the Gotlandian (about 100 meters), Jurassic (660 to 700 meters), Tertiary and Quaternary deposits, whose thickness is some hundreds of meters in various parts of the depression.

The Nyuyoy-Vilyuy depression has a still more complete section: here occur the Lower (2,500 to 2,600 meters) and Upper Cambrian (200 to 300 meters), the Ordovician (about 400 meters) and the Gotlandian (tens of meters), above which in the Kempendyay area and in the region of the middle reaches of the Vilyuy River are situated Devonian (some hundreds of meters), Carboniferous, Permian and Triassic deposits (not less than 200 meters), these being covered by a thick series of Jurassic, Cretaceous, Tertiary and Quaternary deposits (tens to a few hundreds of meters; [1, 3, 15, 16]).

A combination of such formations as molassic, red, terrigenous clastic, saliferous and carbonate rocks is characteristic of the whole lower Paleozoic of the Angara-Lena flexure; the middle and upper Paleozoic are represented by saline rocks, red-colored carbonate rocks and by terrigenous clastic rocks, alternating with pyroclastic formations and layered bodies of trap. The entire Mesozoic section is composed of clastic continental deposits, in places coal-bearing, and including, in the north, some marine deposits.

The outer zone of the Angara-Lena flexure, adjoining the Sayan-Baykal Caledonids, possesses a linear, folded structure which for a long time served as the basis for including this zone in the east Siberian Caledonids. In the central parts of the flexure the folding gradually fades; dome-shaped and swell-like structures prevail here. Finally, in the inner zone of the Angara-Lena flexure there is a system of local folds or "structures of the Litvinsev type, whose constitution has much in common with the so-called ejective folds of the Pre-dural marginal flexure ([1], p. 431).

Various research workers have determined different ages for the fold structures of all types observed within the Angara-Lena flexure. Despite the existence of a number of stratigraphic discontinuities in the Paleozoic section

(for example, the absence or reduction of the middle division of the Cambrian, and the reduction of the Gotlandian, Devonian, Carboniferous and Permian sections), no distinctly regional or angular unconformities have been observed within this multi-kilometer series of sedimentary rocks. If the statement is correct that each principal epoch of folding corresponds to a major regional discontinuity on the platform, occurring immediately after the epoch of folding, then the absence or reduction of the Middle Cambrian, the reduction of the Gotlandian section and, probably, of the lower part of the Devonian section testify to the multiple and complex folding in the zone of the Sayan-Baykal Caledonids. In this respect, the red-colored, saliferous and pyroclastic deposits of the Devonian recently discovered in the region of the middle reaches of the Vilyuy River, in the northern part of the Angara-Lena flexure, is extremely symptomatic [3].

It is certain that most of the linear, dome-shaped and ejective-fold structures of the Angara-Lena flexure originated, strictly speaking, in pre-Jurassic time. This is affirmed by the transgressive deposition of Jurassic formations on the eroded and folded complex of the lower Paleozoic along the periphery of the Vilyuy syncline and the Jurassic Irkutsk depression. But it is also certain that these structures were developed (this is true at least for the Upper Lena depression) in the process of Mesozoic and, probably, later orogenies [2, 8, 9]. The development of folds contemporaneously with Jurassic and, apparently, Neogene sedimentation, observed on the Angara-Lena watershed, testifies to this important and interesting circumstance [2, 4, 8, 9, 18, 24].

The Angara-Lena flexure, whose formation began in some places at the beginning of the Paleozoic era and in others at the end of the Precambrian, and which was continued during a considerable number of geologic periods, is to a certain extent an inherited structure. The outer zone of this flexure (and perhaps also its central part) was situated on territory occupied by the upper Proterozoic (Rifeysk, Siniysk, late Precambrian) geosyncline [12]. In the southern Upper Lena depression, the Lower Cambrian lies with a clearly expressed, regional unconformity on the folded, three-membered Baykal complex [10]. On the southern edge of the northern (Nyuy-Vilyuy) depression, we do not separate in a structural sense the Patomsk complex of the upper Proterozoic from the overlying series of sedimentary rocks of the whole lower Paleozoic, beginning at the lower division of the Cambrian and ending with the Llandoveryan stage of the Gotlandian. The inner and to some extent the central zone of the flexure was, apparently, situated

during the foundation stage on the upper Proterozoic, Rifeysk platform, as may be judged from geophysical and deep borehole data.

In the light of what has been stated, it becomes obvious that associating the Angara-Lena flexure with the ancient marginal flexures of the Baykal (Lower Cambrian) folding is not substantiated. The red-colored molassic and molasse-like formations, which are part of the sedimentary series of this flexure, are not exclusively Lower Cambrian. They belong also to the Upper Cambrian, Ordovician, Gotlandian and Devonian. Apart from the Lower Cambrian, the saliferous formations also exist as well in the Upper Cambrian and Devonian. The molassic coal-bearing formations have the appearance of the Mesozoic deposits of the southern and northern depressions of the Angara-Lena flexure.

The geologic history of various major parts of the Angara-Lena flexure was not similar. The history of the southern depression commenced with the heavy accumulation of sediments in a Lower Cambrian basin, which transgressed the eroded, folded, upper Proterozoic basement. In the northern basin, no folding occurred at the end of the Precambrian and, apparently, the Cambrian marine basin was inherited directly from the previous upper Proterozoic (Rifeysk) stage without any particularly rapid changes. The vigorous sedimentation of the Lower Cambrian epoch was almost totally interrupted in the Middle Cambrian. But no orogenic processes whatsoever were associated with this stratigraphic hiatus—there were no repercussions whatsoever of the "Baykal" folding within the Angara-Lena flexure.

Above the Middle Cambrian, there is conformably placed the sedimentary series of the Upper Cambrian, Ordovician and Gotlandian, within whose sections local and merely stratigraphic discontinuities are observed. The lower age limit of the folding, displayed in different forms in different zones of the flexure, is determined by the time interval from the Wenlockian to the Downtonian, including also, in all probability, some part of the Devonian period. In other words, it is a question of Taconian and, probably, of Ardenian and Erian movements.

In the southern depression, after a long interval corresponding to the greater part of the Gotlandian, Devonian, Carboniferous, Permian and Triassic, the thick fresh-water series of the Jurassic of the Irkutsk basin was deposited on the eroded surface of the gently-folded lower Paleozoic basement. During Jurassic and in places Tertiary sedimentation, a prolonged, arcogenetic process caused the formation [8, 9, 18] of linear fold structures, clearly expressed in the region

of the Angara-Lena watershed. The north-eastern trend of these Mesozoic-Cenozoic folds is the same as that of the folds of the lower Paleozoic basement. That relatively complex system of rather steep, linear folds of the outer zone of the Upper Lena depression, which may be observed at the present time, was shaped only as a result of the renewed orogeny.

The northern Nyuyo-Vilyuy depression of the Angara-Lena flexure was developed in a different way. Here there is not that great stratigraphic hiatus between the Gotlandian and the Jurassic which exists in the southern depression. In the northern part of the northern depression, Llandoveryan deposits are overlain by red, saliferous and pyroclastic deposits of the Devonian, above which lie the Carboniferous, Permian and Triassic [3]. Later on, the new and major structures of the Siberian platform were developed from the beginning of the Jurassic period — the Vilyuy syncline and the enormous Vilyuy-Angara flexure [5].

The Vilyuy Mesozoic-Cenozoic syncline is inherited to a considerable extent from

the older Nyuyo-Vilyuy depression of the Angara-Lena flexure. By all indications the thick Mesozoic sedimentation in the region of the Vilyuy syncline, against the background of its prolonged subsidence, was associated not solely and not so much with movements of the Verkhoysansk geosyncline, as Yu.M. Pushcharovskiy believes [15, 16]. The development of the Vilyuy syncline and the broad Vilyuy-Angara flexure is directly connected in space and time (Fig. 2) with the formation of the major Mesozoic-Cenozoic arcogenetic structure of the Sayan-Baykal arched uplift [8, 9, 18]. By all indications fragmentary material was removed from here to the Vilyuy-Angara Mesozoic flexure and the Vilyuy syncline. Having compared the spatial position of the axes of the ancient, Paleozoic, Angara-Lena flexure and the superimposed, Mesozoic, Vilyuy-Angara flexure, it is easy to recognize the displacement of the flexural axis to the northwest, to the side of the Siberian platform.

On the outer edge of the Siberian platform, partly on the borders of the zone of the Sayan-Baykal Caledonids, the long and unusually wide Angara-Lena flexure was established

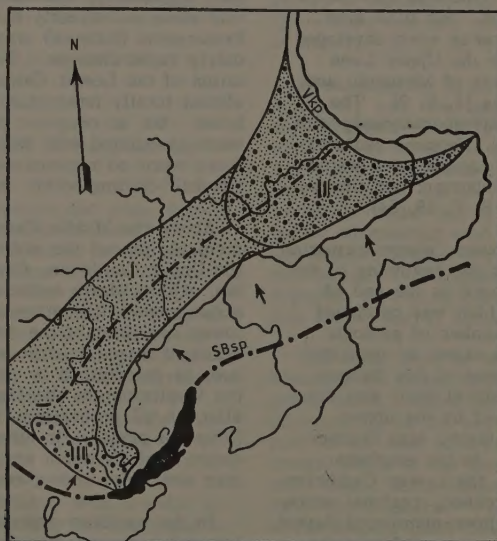


FIGURE 2. Zones of subsidence in the Jurassic (schematic).

I -- Vilyuy-Angara flexure; II -- Vilyuy syncline;
III -- Irkutsk depression;
Vkp -- Verkhoysansk marginal flexure; SBsp -- axis of
the Sayan-Baykal arched uplift.

The direction of removal of fragmentary material in
the flexure is shown by the arrows.

Broken line -- axis of the flexure.

at the beginning of the Paleozoic era (in the southern depression) and at the end of the Precambrian (in the northern depression). This was filled by a thick series of sedimentary rocks which resemble, by their structure and by "the assemblage of the formations," the marginal flexures known on the periphery of the Hercynian, Mesozoic and Alpine zones of folding. It differs from the typical marginal flexures not only by its very considerable width and "too flat character of the folding" ([1], p. 431). The specific character of the Angara-Lena flexure is expressed first and foremost by the unusual duration of its development, measured by many geologic periods or even (in the northern depression) by several eras.

Such boundary structures of platforms and folded (geosynclinal) regions merit their being classified in a special category — zones of pericratonic subsidences. In the Angara-Lena flexure, one is readily convinced of the fact that the development of zones of pericratonic subsidences is clearly connected with the life of the neighboring geosynclinal region. The termination, however, of the geosynclinal regime of the Baykal mountainous tract in the second half of the Cambrian period did not stop the further formation of the Angara-Lena flexure, but only somewhat reduced the tempo of its sagging and the energy of sedimentation. The southern depression of the flexure continued to develop up to the beginning of the Ordovician and again its aptitude not only for epiorogenic subsidences, but also for arcogenetic-type folding, was cut without preliminary preparation in the Mesozoic. In the northern Nyuyo-Vilyuy depression, subsidence and the accumulation of sediments corresponding to it started from the end of the Proterozoic era, and continued with negligible interruptions during the Paleozoic and Mesozoic eras, and also in the Cenozoic. The inherited Vilyuy-Angara flexure, directly associated with the Vilyuy syncline and the Irkutsk depression, was formed in the Jurassic.

It is doubtful whether the Angara-Lena zone is unique. In the search for analogous structures, it is perhaps expedient to note the region of the Pechorsk and Timan synclases, the Glazov syncline, the eastern (Urals region) part of the Volga-Urals syncline and the syncline of the Caspian region. It is possible that one should include in this category just the southeast border of the Eria platform, within which is situated a deep flexure filled by sedimentary rocks of the Torridonian, Cambrian and Ordovician [11, 25, 26, 27].

I think that the theory of the phased development of the Earth's crust [6, 9, 12, 13, 14, 20, 21, 22, 23] may perhaps be supplemented

in the sense that the relationships of platforms and surrounding geosynclinal regions in time and in space are expressed not only in the form of marginal joints and short-lived marginal and transverse flexures: these relationships are also expressed, apparently, in another form — zones of prolonged pericratonic subsidence.

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CARBONIFEROUS DEPOSITS OF THE SLOPE OF THE BALTIC SHIELD AND THEIR BAUXITE CONTENT¹

by

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The earliest information about the presence and character of Carboniferous deposits of the eastern slope of the Baltic shield is published in the works of A.K. Meyyendorf [11], I. Komarov [9], R.I. Murchison [12], G.P. Gel'mersen [5], A.A. Inostrantsev [7] and others.

However, their more or less proven classification found reflection in the works of N.I. Tolstikhin [13] and M.M. Tolstikhina [14] and especially in the researches of V.P. Barkhatova (1931-1934). Somewhat later the study of Carboniferous deposits in the north of the Russian platform occupied E.A. Kal'berg (1937), A.I. Zoricheva (1949), A.I. Lebedintsev (1949), L.Ya. Gol'din (1949-1950), G.K. Frumkina (1949) and A.G. and O.N. Kondiayn (1949-1952).

Finally much prospecting for bauxite, undertaken along the eastern slope of the Baltic shield with our assistance, yielded new and considerable factual material (1949-1956), permitting the stratigraphic subdivision of the Carboniferous in this area to be described somewhat differently and in greater detail.

I express deep gratitude to A.P. Potay, V.P. Barkhatova, K.V. Miklukho-Maklay and G.P. Radchenko for their identification of the fossil fauna and flora that we collected.

CARBONIFEROUS STRATIGRAPHY

To the east of Lake Onega and in the basin of the Onega River (Fig. 1), Carboniferous deposits are represented by all three divisions; the lower division is composed principally of continental argillaceous and arenaceous formations, while the middle and upper divisions consist of marine, almost entirely carbonate, sediments. The Carboniferous deposits extend from the southwest to

the northeast in a belt averaging 120 to 130 kilometers in width. In the area of the Plesetsk River this belt abruptly narrows down to 50 kilometers, but its boundaries gradually open out to the north and south. In riverbeds and on the sides of many large rivers, Onega, Severnaya Dvina, Mosha and others, Carboniferous strata are exposed on the ancient surface; the full thickness of these deposits is revealed in a large number of boreholes, principally in the area of the northern course of the Onega River where I studied them in detail. The generalized stratigraphic scheme of the Carboniferous deposits of the considered area, based on new data, can be seen in Figure 2 (from the bottom upwards).

LOWER CARBONIFEROUS (C₁)

The complete absence of deposits of the Tournaisian stage on the eastern slope of the Baltic shield had been universally recognized up to the present time. By this very fact a rather considerable break in the accumulation of sediments between the Upper Devonian and lower Carboniferous is assumed. Now, as a result of the processing of the macroflora residues that we collected, it is possible to affirm that continental formations of the Tournaisian stage are present in the area of the middle course of the Onega River. The whole of the so-called infra-ore stratum (C₁^{pl}) belongs to these deposits, and possibly also the very lowest part of the kaolin-bauxite stratum (C₁^{kb}). The following plant remains are found in these deposits (identified by G.P. Radchenko): *Lepidodendron* aff. *volkmanianum* Sternberg L. (?) *Heeri* Nathorst, *Ursiella septentrionalis* Radcz., *Bergeria* sp., *Stigmaria ficoides* f. *artica* f. nov., *Pteridrachis striatissima* f. nov., *Cordaites norden-skoldii* Heer, *Platyphyllum* sp., and *Boroviczia mimerensis* Nathorst. The forms of *Lepidodendron* (?) *Heeri* and *Ursiella septentrionalis* are known from a number of localities in southern Siberia and Mongolia where Tournaisian deposits occur. According to the conclusion of G.P. Radchenko, the whole complex

¹ O kamennougol'nykh otlozheniyakh vostochnogo sklonova baltiyskogo shchita v svyazi s ikh boksitonost'yu.

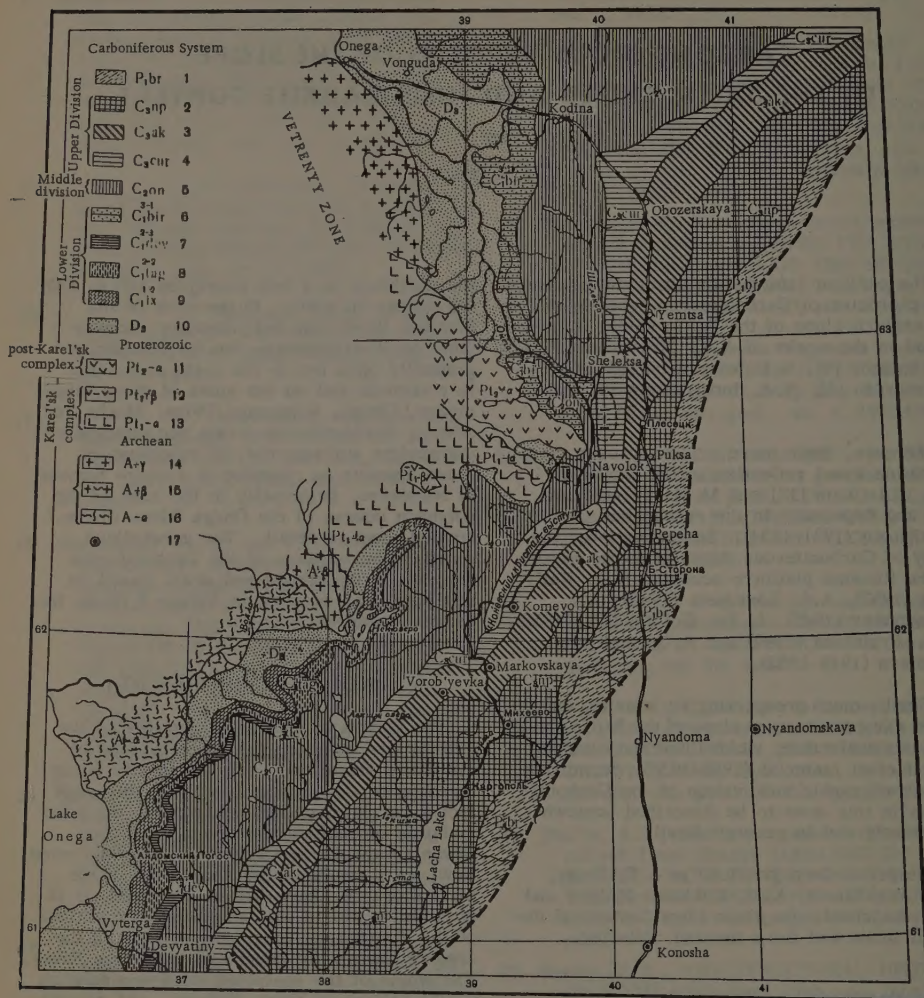


FIGURE 1. Sketch map of the development of Carboniferous deposits on the eastern slope of the Baltic shield.

Carboniferous deposits: 1 -- Borodsvid series; 2 -- Nadporozh series; 3 -- Akulov series; 4 -- Chur'yeg series; 5 -- Onega series; 6 -- Biryuchevo series; 7 -- Devyatiny series; 8 -- Tagazhema series; 9 -- Iksa series; 10 -- upper Devonian.

Proterozoic: 11 -- basalt and diabase; 12 -- gabbroic diabase; 13 -- spilite.

Archean: 14 -- Onega granite and migmatite; 15 -- granitoid gneiss; 16 -- gneiss and migmatite; 17 -- deep boreboles.

Depressions: I -- Denislavsk; II -- Iksa; III -- Shbozersk.

FIGURE 2. Stratigraphic scheme of classification of deposits of the eastern slope of the Baltic shield.

1 -- dolomite, dolomitized limestone, rubbly organic limestone with *Productus cora*, *Chorisitit* *trarentis* and brachiopods; fauna of *Stafella*, *Zaphrentis*, *Productus cora*, *Chorisitit* *strautshold*;
2 -- dolomitized limestone and dolomite with layers of clay and marl, rubbly organic limestone alternating with marl and clay with fauna residues: *Choristes traushold*, *Ch. onegenesis*, *Productus akulovensis*; 3 -- thinly laminated limestone with a finely crystalline texture and with layers of dolomite; fauna: *Productus donetzianus*, nuclei of gastropods, *Murchison* sp.;
4 -- finely crystalline and dolomitized limestone with layers of rubbly organic limestone; fauna: *Choristes mosquensis* Fisch., *Spirifer tegulatus* Trd., *Productus* ex. gr. *donetzianus* Zich.; 5 -- dolomite and dolomitized limestone with the following fauna: *Choristes mosquensis* Fisch., *Spirifer tegulatus* Trd., *Productus* (*Dictyoclostus*) *infloctiformis* Ivan.; 6 -- coarse, rubbly and organic limestone with an abundant fauna: *Choristes mosquensis* Fisch., *Spirifer tegulatus* Trd., *Martinia* sp.; reef limestone packed with bryozoa (*Fenestella veneris* Eichw.), finely crystalline limestone with an aphanitic texture;
7a -- dolomitized and silicified limestone of a conglomeratic texture with infrequent residues of *Choristes priscus* Fisch.; 7b -- violet, orange and red clay with limestone fragments; 8 -- at the base, conglomerate; above, bluish white clay; still higher, beds of interstratified clay, silt, and siltstone; at the very top (2 to 3 meters thick), marly and dolomitic rocks; 9 -- mottled beds, represented: at the base by interstratified conglomerate, gravel, sandstone, dolomite and limestone; in the middle part are two characteristic bands of conglomerate, composed of well-rounded pebbles of diabase cemented by calcareous and siliceous material; the upper beds are represented by fine-grained reddish brown sandstones; 10 -- gray-brown limestone, strongly karstic and weathered, with rare residues of brachiopod faunas: *Productus* (*Gigantella*) *latissimus* var. *typica* Sar.; 11 -- dense and plastic clay; strongly dolomitized limestone; sandy-clayey deposits; dolomitized limestone with *Productus giganteus* Mart.; sand, clay, sandstone; coralline bryozoan or foraminiferous limestone; 12 -- sandy clay with lenses of siltstone, more rarely with bands of clayey sandstone; 13 -- series of ferruginous clays with disseminated pisoliths; 14 -- kaolin-bauxitic series: siallite, allite, bauxite; 15 -- white and gray kaolinic clay, sometimes with bands of siltstone; 16 -- sandy-clayey mottled series.

Group	System	Division	Stage	Substage	Series	Subseries	Horizon	Variation in thickness, m.	Column (scale 1:500)
Toumazian	Paleozoic (Pz)	Carboniferous (C)	Upper (C ₃)	Gzhel'sk (C ₃ ²)	Akulov (C ₃ ak)	Nadporozhye (C ₃ nad)	0-40.0	0.0-40.0	1
									2
									3
									4
			Middle (C ₂)	Moscow (C ₂ m)	Orenga (C ₂ on)	Karelin (C ₂ kar)	15-25	10-20	5
									6
									7
									8
			Lower (C ₁)	Vissean (C ₁ ^{1v})	Tagazhensk (C ₁ ^{1v} tag)	Devian (C ₁ ^{1v} dev)	0-25	0-25	9
									10
									11
									12
			Lower (C ₁)	Vissean (C ₁ ^{1v})	Tagazhensk (C ₁ ^{1v} tag)	Devian (C ₁ ^{1v} dev)	0-25	0-25	13
									14
									15
									16

upper Devonian

of plant remains is characteristic of the Medvezh unit of the Tournaisian stage.

Similar flora were found by us in the very lowest part of the kaolin-bauxite stratum. Hence we concluded [10] that the formation of the infra-ore stratum dates from Kizelovsk time; the kaolin-bauxite stratum was laid down at the end of Tournaisian or at the very beginning of Visean time, being replaced upwards by the stratum of ferruginous clay and still higher by the supra-ore stratum, whose formation was apparently completed by the end of Tula time.

Thus, in the very basal part of the Carboniferous section we distinguished [10] the Iksa series, comprising the following strata (from the bottom): a) infra-ore (C_1^{1np}), b) kaolin-bauxite (C_1^{1-2kb}), c) clay with iron pisoliths (C_1^{2zhb}) and d) supra-ore (C_1^{2nr}). According to its stratigraphic content, the given series corresponds to the Kizelovsk unit which together is assigned to the coal-bearing and Tula units of the Visean stage of the unified scheme.

1. Iksa Series (C_1^{1-2ix})

a. The infra-ore stratum (Upper Tournaisian stage) is composed of light clay with plant remains, these mostly having a light gray color although they are occasionally almost white with a pinkish hue; the clay is somewhat greasy to the touch. Its upper boundary is defined arbitrarily, because in lithologic composition this clay is not different macroscopically from the overlying kaolin-bauxitic stratum, especially where the latter has a light gray color. A bluish gray layer of fine-grained siltstone is observed in places between the kaolin-bauxitic and the infra-ore strata, with a thickness of 0.05 to 0.010 meter. In places the infra-ore stratum consists of mottled clay containing siltstone bands, and then its lower boundary is no longer clear, although the underlying beds of the Upper Devonian are always identified comparatively easily by the presence in them of fine scales of mica, which are absent in the infra-ore stratum. The infra-ore stratum has a thickness of from 0.2 to 5 meters and very rarely of 15 meters. The clay of this stratum consists almost exclusively of kaolinite with sharp, hexagonal, plate-like outlines, which are visible in an electron microscope and which indicate their chemical precipitation. The kaolinitic composition of the clay is confirmed by an exothermal effect that is typical of kaolinite.

By the proportion of minerals entering into the light fraction, the clay of the given stratum differ markedly from those of the Upper Devonian, as shown in Table 1.

Table 1

Minerals of the light fraction	Clay of the infra-ore stratum (in %)	Clay of the upper Devonian (in %)
Quartz	3.5	67.1
Kaolinite	82.2	0.0
Colored mica	0.0	5.1
Feldspar	trace	8.9

Near the protrusions of the crystalline basement, the infra-ore stratum is represented in places by more coarsely clastic material, which L. Ya. Gol'din (1949) mistook for breccia.

b. The kaolin-bauxitic stratum (Tournaisian-Visean) is present in the area of the middle reaches of the Onega River, above the infra-ore bed, and has a thickness of 5 to 25 meters. The stratum is composed of kaolinitized clay, siallite, allite and bauxite, macroscopically distinguished with difficulty from each other and which are irregularly-colored, finely-dispersed, clay-like formations. These rocks most frequently have a stony texture, but friable and clay-like sediments are present in places.

It is possible to distinguish five main groups of rocks in terms of coloring:

1 — white with pinkish, yellowish and greenish hues; 2 — gray with light, dark, lilac, greenish and coal-black hues; 3 — yellow with a varying intensity down to dark brown; 4 — red color with cherry-red, sealing wax-red and brown-red hues; 5 — irregular and spotty coloring.

With respect to the degree of coherency and texture, it is possible to distinguish 12 varieties of rocks: 1 — stony dense or finely-oolitic texture; 2 — coarsely fragmental and brecciated texture; 3 — finely brecciated texture ("siallitic breccia"); 4 — pisolitic texture; 5 — pea texture; 6 — with the rhizoids *Pteridorachis*; 7 — with horizontal or approximately horizontal bedding; 8 — with inclined bedding; 9 — with steep bedding; 10 — feebly stony texture; 11 — friable texture; 12 — with a clay-like habit. The bauxites are, as a rule, found in the middle part of the vertical section. Upwards and downwards they gradually grade first into allite and then into siallite. A similar succession is observed also in a horizontal direction: the maximum thickness of the bauxite layer is concentrated in the center of the deposit. This zoning in the bauxite and bauxitic rock sequence is explained, evidently, by the uneven concentration of aluminum in the

Table 2

Rocks	Kaolinite	Gibbsite	Bohemite	Goethite	Carbonates	Oxides of silicon	Oxides of titanium	Remainder
Kaolinitic clay	75.4	—	—	22.4	0.5	0.2	1.3	—
Ferruginous allite	40.1	4.7	19.8	61.5	0.6	0.4	2.10	0.8
Gibbsitic bauxite	19.2	45.2	4.9	27.7	0.5	0.3	2.0	0.2
Bohemitic bauxite	48.4	13.0	30.9	4.4	0.3	1.0	3.1	—

solutions entering the aqueous basin at different times.

Within the deposit on the eastern slope of the Baltic shield the bauxite forms a single layer, although in places this layer is split and allite occurs between the bauxite.

According to data of the Northern Onega expedition of the Northwestern Geological Department, the mineralogic composition of the rocks constituting the kaolin-bauxitic stratum is as shown in Table 2.

The rock-forming minerals of the kaolin-bauxitic stratum are kaolinite, hydrohematite, goethite, and to a lesser degree (principally for bauxite) bohemite and gibbsite. An elevated content of chromium is also noted here (up to 4%).

In granulometric composition, the rocks are characterized by a high content of clay (35 to 75%) and silt fractions (25 to 65%). Kaolinitized clays are also noted in the very lowest and highest parts of the stratum, which on the whole is composed of allite and siallite, with lenses and sheet-like beds of bauxite.

c. Within the area in question the stratum of ferruginous clay is more widespread than the kaolin-bauxitic stratum, on which it is also deposited. In those places where the kaolin-bauxitic stratum is absent, the stratum of ferruginous clay overlies the infra-ore stratum.

The stratum is composed of silty and mottled clay, characterized by the fine dispersion (the rocks consist of 30 to 45% of the < 0.01 millimeter fraction and 50 to 70% of the 0.1 to 0.01 millimeter fraction) of their constituent clastic material and by the presence of iron pisoliths, disorderly disseminated throughout the whole mass of the clay, or concentrated into separate horizons in the form of thin layers with a thickness of 0.2 to 1.2 meters; clays with a content of both

layers of pisolitic iron-ore and discrete pisoliths of iron, dispersed throughout the whole stratum, are frequently encountered.

In the iron-ore beds, clayey-ferruginous, clayey-gypsiferous or, considerably more rarely, kaolinitic material serves as the cement. The iron pisoliths have a circular or circular oblong form with a smooth and bright surface, which becomes dull and rough on weathering, the color of the pisoliths is dark gray or red-brown; their size ranges from 1 to 12 millimeters, but is mostly 2 to 3 mm. The shell of the pisolith consists of a ferruginous clayey substance, and its body of hydrogoethite and goethite. A small grain of quartz or clayey material is usually found in the center of the pisolith. According to the data of the Northern Onega expedition, the chemical composition of the pisolitic iron ores is as follows: SiO₂, 20.9%; TiO₂, 0.3%; Al₂O₃, 12.3%; Fe₂O₃, 49%; FeO, 0.5%; Cr₂O₃, 0.5% MnO, 1.3%; MgO, 0.6%; CaO, 1.4%; and NiO, 0.4%.

The average thickness of the stratum is 5.0 meters (from 0.5 to 23 meters). Its age corresponds to the end of the coal-bearing time of the unified classification.

The boundaries of the stratum of ferruginous clays are not altogether clearly expressed lithologically, although they are distinguished fairly easily by the iron pisoliths and layers of pisolitic iron ore. Within the Iksa depression, a layer of unevenly-grained quartz sandstone with a ferruginous cement is present in the lowest parts of this stratum; the sandstone also contains a considerable quantity of disseminated (in places concentrated into a single layer) pisoliths of iron.

Fine-grained quartz sand or sandstone, also containing dispersed pisoliths of iron, are common in the upper part of this stratum. In such cases, the boundary of the stratum of ferruginous clays is distinguished more easily.

1) Supra-ore stratum. Between the stratum

of ferruginous clay and the base of the overlying Devyatynny limestone are argillaceous and arenaceous deposits with a thickness of from 2 to 18 meters (Shirbozersk depression). They are characterized by coarser clastic material than is found in the underlying rocks and by the hydromicaceous clay lenses, consisting of siltstone with layers of clay, sand and sandstone. Sand and sandstone are developed in the lower and upper parts of the section, and clay in the middle part. The supra-ore stratum tops the section of the Ikksa series.

The bauxite-bearing zone does not have a continuous development throughout the eastern slope of the Baltic shield. In the north it is bounded by outcrops of basic crystalline rocks of the Vetrenyy zone, and in the south closely approaches the Konevsk protrusion of the crystalline basement; its distribution in the Kenozersk, Shirbozersk and other large depressions has been insufficiently studied.

The bauxite deposits of the eastern slope of the Baltic shield are adapted geomorphically to marginal zones of semi-closed or closed depressions (more rarely to small hollows) that are well expressed in the topography of the crystalline basement; during the search for bauxitic deposits it is very important, therefore, to expose the hidden topography of the basement surface.

According to our ideas, the Patrovsk series in the scheme of V.P. Barkhatova [4] corresponds to the upper, larger half (clearly within the Yasno-polyansk substage) of the Ikksa series, and it is naturally assigned to the subseries in our scheme.

The correctness of the deduced comparison is confirmed indirectly by the stratigraphic position of the stratum of ferruginous clay in the structural sections of the boreholes drilled between Plesetsk station and the town of Kargopol'. In each of these boreholes, the supra-ore and ferruginous clay strata are revealed beneath the lower carbonate layer of the Tagazhema series. Thus the Patrovsk subseries is intersected at a depth of 98.7 to 115.8 meters (17.1 meters) in the section of Borehole 2510. Its stratigraphic position here is determined rather easily: upwards by the presence of the lower carbonate layer and downwards by the mottled stratum of micaeous clay of the Upper Devonian.

In the interval between 98.7 and 102.1 meters, the Patrovsk subseries is composed of reddish brown sandstone and clay with a crumpled texture — the analogues of the clay of the supra-ore stratum (C_{12nr}) of the Ikksa depression in the bauxite-bearing zone. Lower down (102.1 to 104.7 meters) follow clays that are extremely typical of the stratum of

ferruginous clay; still lower is a sandstone band with a thickness of 0.3 meter (between 104.7 and 105.0 meters), also containing disseminated pisoliths of iron with dimensions of 1 to 3 millimeter.

In the interval between 105.0 and 105.3 meters a layer of pisolitic iron ore (0.3 meters thick) is present, within which the pisoliths constitute upwards of 40% of the total mass of the rock. The stratum of ferruginous clay is observed to a depth of 113.6 meters. This is underlain by a bed of clay reminiscent of the infra-ore stratum of the Denislavsk depression. Then follows the argillaceous arenaceous stratum of the Upper Devonian.

Within the section of borehole 2509-s, the Patrovsk subseries occurs in the interval between 116.6 and 131.9 meters (15.3 meters thick) beneath a bed of breccia which separates it from the overlying Tagazhema series. The stratum of ferruginous clay is present here at a depth of 123.50 to 126.25 meters (2.75 meters thick). It is overlain by sandstone; it is underlain by kaolinitic clays of the infra-ore stratum (C_{11pr} 129.6 to 131.9 meters). A band of siltstone (between 126.25 and 129.60 meters) occurs between these clayey strata. Finally the stratum of the ferruginous clay of the Patrovsk subseries is disclosed in the interval between 156.8 and 158.5 (1.7 meters thick) within the section of Borehole 2507. This stratum rests on sandy deposits of the same subseries, and is covered by clays of the supra-ore bed (C_{12nr}).

As we have seen, the kaolin-bauxitic stratum is absent here in all cases. However the considerable distance between the cited boreholes and the presence of ferruginous clay in these sections permits one to consider that the bauxite content in the area to the south of the Vetrenyy zone merits further study.

Of definite interest is one section of a deep borehole, in which "bauxite-like" white clay with plant remains is recorded between depths of 490.95 and 493.95 meters (3 meters) amidst continental deposits of the lower Carboniferous. This clay is overlapped (between 389.0 and 490.95 meters) by similar white siltstone with a kaolinitic cement. Below (493.95 to 507.8 meters), there occurs a stratum of interbedded clay and siltstone. Apparently, this section down to the interbedded stratum corresponds to both the infra-ore and kaolin-bauxitic strata of the Ikksa series of the bauxite-bearing zone. Therefore it should be examined and tested for bauxite.

The full section of the Ikksa series is also present along the axis of the Shirbozersk depression for its whole extent (Fig. 3). Here the thickness of the infra-ore stratum is larger than usual (up to 15 meters).

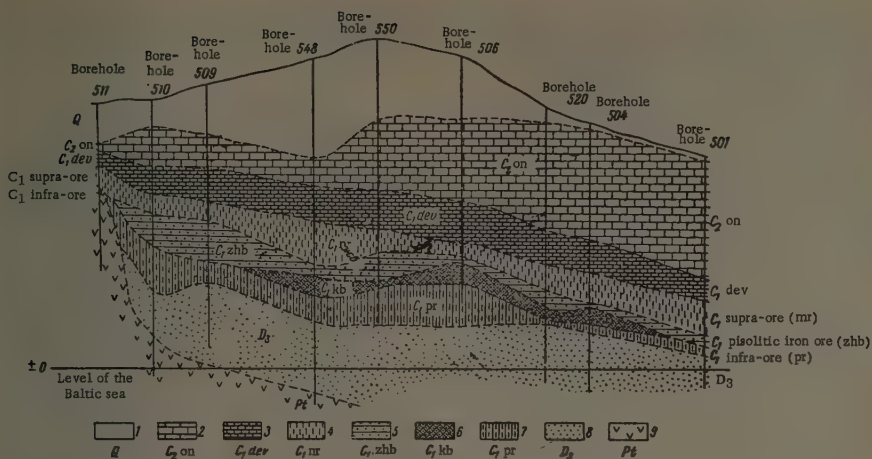


FIGURE 3. Shirbozersk deposit. Geologic section. Horizontal scale 1:100,000.

1 -- Quaternary deposits; 2 -- limestone of the Omega series; 3 -- limestone of the Devyatin series; 4 -- sandy-clay supra-ore stratum; 5 -- clay containing layers of pisolitic iron ore; 6 -- kaolin-bauxitic stratum; 7 -- sandy-clay infra-ore stratum; 8 -- sandy-clay stratum; 9 -- crystalline rocks of the basement.

In the deep Nyandoma borehole section, B.P. Barkhatova [3] believes the sandy-clay deposits, which have a thickness of 15.7 meters and which overlie the mottled stratum of the Devonian (327.8 to 343.5 meters), belong to the Patrovsk subseries (C_{1par}). The basal part of these deposits is represented by light yellow, almost white sandstone and sand, while the remaining part consists of violet-red clay with a conchoidal fracture. The deposits of this subseries are exposed in the southern part of the territory under consideration, in the valleys of the Nozrek, Tagazhema, Lema, Andoma and other rivers. According to the data of V.P. Barkhatova [4], the Petrovsk subseries is composed here of clay, sand and sandstone, whose overall thickness is 40 meters. Lenticular clay beds constitute the very lowest part of the section, being represented by black refractory varieties and, in places, by distinctly red colcothars; the thickness of the clay is 3 to 10 meters. Above the clay, a bed of quartz sand (15 to 20 meters) with fine layers and lenses of variegated plastic clay is present.

The upper part of the subseries (15 meters) consists of a stratum of interbedded sand, clay (these predominate) and calcareous sandstone with impressions of *Productus* ex gr. *scabriculus* Mart.

Paleontologically, the Petrovsk subseries is not characterized by a paucity of organic remains.

VISEAN STAGE (C_1^2)

2. Tagazhema Series (C_1^{2tag})

According to the unified scheme for the Carboniferous of the near-Moscow basin (1951), the Tagazhema series of V.P. Barkhatova corresponds to the Tarusa unit. In other schemes it is compared with the Somba series of A.G. and O.N. Kondiayn (1952), with E.A. Kal'berg's (1939) Laysk series of the Onega Peninsula and with the Oka substage in the scheme of A.I. Krivtsov [10].

Deposits of the Tagazhema series are absent in the bauxite-bearing zone; their natural outcrops are found in the southern part of the territory in question, where they have been well studied by V.P. Barkhatova. Deposits of the Somba series are exposed in the Somba River, a left tributary of the Onega River, while rocks of the Lae series outcrop on an ancient surface in the Onega Peninsula.

V.P. Barkhatova [4] has divided the deposits of the Tagazhema series into six strata (a, b, c, d, e, f): three (a, c, e) are composed of limestone and dolomite and three (b, d, f) of sandy-clay formations. Organic remains occur only in carbonate rocks and their forms are as follows: *Productus* (*Gigantella*) *gigantus* Mart. var. *typica* Sar., *Pr.* (*Gigantella*) *latissimus* Sow. var. *prisca* Sar., *Pr.* (*Striatifera*) *striatus* Fisch, var. *lata* Jan., *Pr.* (*Linoproductus*) *tenuisustriatus*

Vern., Martinia angulosinulata Jan., Lonsdaleia floriformis Flem., Chaetetes radians Fisch., Dibunophyllum sp., Zaphrentis sp., Endothyra crassa Brady, Climacamina forschii Mich. and Orbis rotundatus Brady.

The Somba series, which is exposed also along the Onega River between the mouths of the Teksa and Gusev, is represented in the lower part of the section by a mottled stratum of interbedded conglomerate, limestone, dolomite and gravel, the upper part consisting of conglomerate with a calcareous cement and fine-grained reddish brown sandstone. According to our field observations in the area, it is appropriate to mention that the so-called Somba series of A.G. and O.N. Kondiayn immediately overlies the Devyatiny limestone and is the lower part of the Biryuchevo series, which corresponds to the Lower Namurian substage. In the north this same part of the Biryuchevo series completely corresponds to the Laysk series of E.A. Kal'berg, usually formed almost entirely (along the Laya and Echa rivers and in the Onega Peninsula) of dark red or black thinly-bedded sandstone with a poorly-graded granular composition. In places these sandstones have a pisolitic structure.

Apart from natural outcrops, the full thickness of the deposits of the Tagazhema series is penetrated by a number of those same structural boreholes that disclosed the Patrovsk subseries. In lithologic composition this series appears to be rather weathered throughout almost all the southern half of the area; it is represented by dense violet-red clay intermingled with quartz sand. Two or three bands of strongly dolomitized and arenaceous limestone are persistent members of the series. In the limestone revealed in Borehole 2507, I detected the remains of these foraminifera (identified by K.V. Miklakho-Maklay): Eostaffella sp. cf. prisca Raus., Endothyra ex gr. crassa Brady, E. sp., Hyperacumina vulgaris Raus. et Reitl. These forms are characteristic of the Visean stage of the lower Carboniferous.

In the section of the deep Nyandoma borehole the overall thickness of the Tagazhema series is 22.60 meters (depth of 305.25 to 327.85 meters). In other deep boreholes this same series is located at the following depths: Borehole 2510, 78.7 to 98.7 (20 meters); Borehole 2509-C, 76.75 to 116.60 meters (40.15 meters); Borehole 2508, 77.4 to 111.6 meters (34.2 meters); Borehole 2507, 127.0 to 195.9 meters (25.9 m); Borehole 2506, 152.80 to 183.25 (30.45 meters).

The exposed part of the Tagazhema series in the north of the territory under study is restricted by the area of Koneva village. In the Shirbozersk section and in the whole area

north of this section, deposits of the Tagazhema series were not discovered.

3. Devyatiny Series ($C_1^{2-3 dev}$)

V.P. Barkhatova [4] compares this series with the Steshev unit plus the Protva unit of the unified classification for the near-Moscow basin. According to our data, it corresponds to the time of the Serpukhov substage.

Deposits of the Devyatiny series are present along the whole length of the Carboniferous formations (see Fig. 1), but their lithologic composition for the northern and southern slopes of the Vetrenyy zone is different. South of this zone the Devyatiny series is represented almost entirely by carbonate rocks, whereas to the north it consists of terrigenous and rubbly sediments. One of the peculiarities of the deposits of this series in the zone of bauxitization is the complete absence of organic remains; another peculiarity is the presence of the identical fauna in the more southerly part of the area; along their whole length the limestones are silicified and strongly karstic. No large hollows are found, however, since they are all filled by introduced sandy-clay. Natural outcrops of the rocks of this series occur in the valleys of the Vytegra, Nezreka, Porzhinka and other rivers. Their overall thickness is more than 20 meters, and in the Iksha and other depressions (Denislavsk, Shirbozersk), 7 to 18 meters.

In the southern part of the area under consideration, V.P. Barkhatova subdivides the deposits of the Devyatiny series into three strata (a, b, c). The lowest (a) is represented by strongly dolomitized limestone and dolomite of a farinaceous texture with yellow or light gray hues, and with fine impressions of Productus (Striatifera) sp. and Bellerophon sp. The middle stratum (b) is composed of dolomitized, finely-crystalline limestone with the remains of these forms: Productus (Gigantella) latissimus Sow. var. typica Sar., Pr. (Striatifera) striatus Fisch. var. lata Jan., Athyris sp. and Cyrtina sp. Reef-like massive limestone with voids filled by clay usually comprise the upper stratum (c), in which the remains of these corals are present: Chaetetes radians Fisch., Lonsdaleia floriformis Flem., Dibunophyllum sp., Zaphrentis sp. and Michelina sp.

Within the Iksha depression, the Devyatiny series is composed of brown-gray, very dense cryptocrystalline limestone with concretions and nodules of black, more rarely red silica with organic remains. However, the matrix with this appearance is only preserved in separate, extremely limited parts of the area where the Devyatiny series is developed; the

same rocks of this series are usually represented in the lower half of the stratum by a marly-clay mass containing limestone fragments.

The upper half of the Devyatiny series is composed of strongly weathered and karstic limestone with a bluish green (in the Tarasov area) or pinkish-gray color. The small voids and karst channels are filled by introduced clayey material. The limestone is converted into a clayey mass with a distinctly bluish green color in some areas. In general appearance, these rocks resemble the nickeliferous ores of the Ufaleysk type. However, their spectroscopic and chemical analyses showed that they contain low percentages of: Ni, up to 0.006%; Co, up to 0.002%; Cu, up to 0.015%; and CrO, up to 0.05%.

Within the Denislavsk depression, the Devyatiny series is represented by brown-gray cryptocrystalline limestone of a very dense texture, with layers of black and dark-brown silica having a thickness of 0.01 to 0.05 meter. Interbedded limestone, dolomite and marl are present in individual places.

I detected in limestone of the Devyatiny series, the remains of poorly-preserved brachiopods and ostracods (*Spirifer* sp., *Brachithyrina strangwaysi* Vern.), and also the foraminifera *Parastaffella* (?) sp., *Archaeodiscus* sp., *Eostaffella* (?) *glomospira* sp. and *Tolypammina* sp.

Within the Shirbozersk depression, limestones of the Devyatiny series are strongly leached and are commonly converted into a marly rock, while the maternal rock consists of gray, fine-grained, crystalline limestone with a greenish hue.

South of the Shirbozersk depression, deposits of the Devyatiny series are penetrated in their entire thickness by the deep boreholes mentioned above. It is possible to present the general appearance of these deposits by a description of the core from Borehole 2508. Here the Devyatiny series was detected at a depth of 63.5 to 77.4 meters (23.9 m) and is composed of strongly weathered karstic limestone with a cryptocrystalline structure, silicified in places. The voids in the limestone are filled by clearly introduced, reddish brown, calcareous clay. In the limestone, I found the remains of the foraminifera *Parastaffella* cf. *struvei* (Moell) and *P.* sp., which do not occur below the Visean stage, as confirmed by the stratigraphic position of the series.

The Devyatiny series tops the section of the lower Carboniferous on the southern slope of the Vetrenyy zone. Signs of subaerial weathering, fixed on the upper surface of the

limestones of this series, testify to the existence here of a break in sedimentation at the boundary of the lower and middle Carboniferous.

Somewhat different paleogeographic conditions arose during this time in the territory to the north of the protrusion of crystalline rocks of the Vetrenyy zone. Throughout early Namurian time there remained here a shallow sea, whose shoreline often moved first to one side, then to the other, as indicated by the repeated alternation of coarsely terrigenous material with marine carbonate sediments. These unusual littoral-marine sediments have been noticed for a long time and are allotted to the so-called Biryuchevo series, with which the lower Carboniferous deposits are terminated in the northern part of the territory under consideration.

4. Biryuchevsk Series (C₁³⁻¹ bir)

By their stratigraphic position, the Biryuchevsk series corresponds to the Protva unit of the Lower Namurian of the unified classification for the near-Moscow basin, since they are deposited directly on limestone of the Devyatiny series (C₁^{2-3dev}). This series was for a long time assigned to the Upper Devonian, then to the lower Carboniferous, recently to the bottom of the middle Carboniferous, and, finally, some geologists (E.A. Kal'berg, A.G. and O.N. Kondiayn, M.M. Vermolayev and others) proposed to drop the term "Biryuchevsk series" entirely, having divided it into two new series of different ages.

However, the extremely unusual bed of clayey-sandy-carbonate and littoral-marine sediments, at one time named the "Biryuchevsk series," exists in nature and its stratigraphic position, at least at the base, has been established with sufficient precision. The relations of the Biryuchevsk and Devyatiny series may be observed in a number of natural exposures on the left bank of the Onega, in the area of the Zvoz and Biryuchevsk villages. No noticeable discontinuity between these series has been observed.

There was, evidently, no break in sedimentation on the northern slope of the Vetrenyy zone in post-Devyatiny time, as a result of which deposits of the Biryuchevsk series conformably overlie Devyatiny limestone. The upper boundary of the Biryuchevsk series remains obscure, because it is covered directly by Quaternary formations. It should also be noted here that in our opinion a number of discrepancies are probable, in the description of the Biryuchevsk series of the Onega River basin.

During the very thorough investigation of

this area in 1954, I nowhere succeeded in discovering the occurrence of deposits of the Biryuchevsk series immediately over the crystalline basement or Devonian formations; the overlapping of these deposits by rocks of the Podol'sk unit was also not observed. Meanwhile Ye. A. Ivanova and I. V. Khvorova write: "Below carbonate rocks with a fauna of the Podol'sk stage is a thick sequence of terrigenous formations, occurring either on crystalline rocks or on deposits of Devonian age. This sequence is named the Biryuchevsk series" ([6], p. 37). Unfortunately the authors do not indicate the concrete position of this kind of relationship between the Biryuchevsk series and the underlying and overlying deposits. Moreover, according to our data [10], carbonate rocks occupy an important place in the Biryuchevsk series, whereas Ye. A. Ivanova and I. V. Khvorova think that it is composed of terrigenous formations. It is also impossible to confirm the correctness of their assertion that "a characteristic feature of the development of the series is the transition from coarsely fragmental to fine material, although this process did not proceed at all smoothly, being complicated by a certain pulsation in lithogenesis" ([6], p. 38).

As an illustration of the lithologic composition of the Biryuchevsk series and its relationship with the Devyatiny series, apart from my already published section [10], we present a description of a natural outcrop on the left bank of the Onega River, opposite the village of Zaleushka (exposure 8, see below).

QUATERNARY FORMATIONS

1. Plant layer; 0.2 meter.
2. Sandy clay, reddish brown; 1.3 meters.

Biryuchevsk Series ($C_1^{3-1\text{ bir}}$)

3. Dolomitic, motley-colored marl (of a pinkish hue), with fragments of brecciated dolomite having a size of 2 to 7 millimeters and with a stony, dense texture; 10.9 meters.
4. Grayish green conglomerate of limestone pebbles, with a size range of 5 to 12 millimeters and a circular and elongated form; calcareous cement of medium strength; 1.5 m.
5. Reddish white limestone of a cryptocrystalline texture, with an uneven splintery fracture, strongly leached, slightly dolomitized and without conspicuous organic remains; 0.4 m.
6. Slightly calcareous, dolomitic marl of a mottled hue, with a predominant greenish gray color; 0.4 meter.
7. Very arenaceous limestone with fine (1 to 2 millimeters) veinlets of calcite, brecciated texture, fissured; small clayey prisms

are present along the walls of the fissures; 1.0 meter.

8. Calcareous, greenish gray marl with 5 to 10 centimeter thick laminations; limestone of a weakly stony texture; 1.2 meters.
9. Conglomeratic limestone; brick-red limestone pebbles, the pebbles of other rocks bluish green; 0.25 meter.
10. Conglomerates of small calcareous pebbles having sizes of 5 to 7 centimeters; cement also calcareous; 0.35 meters.
11. Arenaceous limestone, brecciated, with an uneven fracture, greenish gray with brown spots and designs; 0.5 meter.
12. Dolomitic marl, slightly calcareous, brick-red, with a stony texture; a greenish gray hue predominates in the upper part of the bed, where fine (0.10 to 0.15 meter) layers of very clayey, weathered dolomite are also present; 3.5 meters.

13. Olive-green, cryptocrystalline dolomite with brick-red spots and small veinlets (1 to 2 millimeters) of calcite; 4.6 meters.

14. Dark-brown, coarsely foliated and banded clay; thin films of reddish brown marshallite with rare crinoidal remains in the foliation planes; 3.2 meters.

15. Unevenly grained, olive-green sandstone with predominantly small grains and a calcareous cement of a pseudo-oolitic structure and medium strength; 0.5 meter.

16. Motley colored conglomerate with a predominantly reddish brown hue; limestone pebbles of a medium degree of rounding and a circular form, with a size of 7 to 12 millimeters; 0.2 meter.

17. Conglomeratic limestone, brick-red in the upper part of the layer and olive-green in the lower part; 0.6 meter.

Devyatiny Series ($C_1^{2-3\text{ dev}}$)

18. Greenish gray, fine-grained and finely-crystalline limestone with an uneven splintery fracture, fissured; 1.3 meters.

MIDDLE CARBONIFEROUS (C_2)

MOSCOW STAGE (C_2^2)

5. Onega Series ($C_2^{2\text{ on}}$)

During the prolonged period of time (deposits of the Upper Namurian substage, all the Bashkir stage and the base of the Moscow stage – the Vereya unit – are missing from the section), the area in question remained dry land after the accumulation of the Devyatiny formations in the south and the Biryuchevsk

formations in the north. The marine transgression only penetrated to here at the beginning of Kashira time. Now these circumstances find confirmation in paleontologic material, not only for the southwest part of the area but also in the middle course of the Onega River. The remains of foraminifera, collected by me in 1954 from the cores of many deep, prospecting boreholes, show that the deposits related to the Onega series contain forms characteristic of the Kashira, Podol'sk and Myachkov units of the unified classification for the near-Moscow basin.

Thus, according to our data, the Onega series corresponds in its stratigraphic content to the enumerated sequences taken together, and thereby includes all four of the series (Kayrocheysk, Karel'sk, Sondol'sk and Zinovsk) of V.P. Barkhatova. V.P. Barkhatova has recently transferred the enumerated series to the class of a subseries.

Natural outcrops of the deposits of the Onega series are very rare within the territory of interest to us. Nevertheless, they are present along the Chur'yeg River between the villages of Gar' and Kuz'minskaya, along the Sondoma, Malaya and Bol'shaya Onega Rivers, in the area of the Biryuchevoy rapids, as well as above the village of Mushka and below the village of Mukhino Gorky, at the very mouth of the Iksha River (Tarasovka village), in the Mushka and Igrema Rivers and elsewhere on the watershed between the Vytegra and Kovzha. The full thickness of the Onega series was penetrated by a large number of boreholes during the prospecting for bauxite along the eastern slope of the Baltic shield. The rocks of the series are represented here principally by limestone and considerably more rarely by dolomite with bands of marl. These rocks contain an abundant but rather similar fauna mainly of brachiopods and foraminifera, with the addition of small amounts of gastropods, fewer pelecypods but also bryozoa and crinoids. Productid and Spiriferid brachiopods play an important role, as do the foraminifera *Staffella*, *Bradyina* and *Climacammina*.

In the Onega region and in the upper reaches of the Onega River, the lower part of the Onega series is assigned by V.P. Barkhatova to the Kayrocheysk subseries (formerly to the Kayrocheysk series), which, according to her description, is composed at the base (3 to 6 meters) of violet, orange, and red clay with limestone fragments without organic remains. Judging from their character and from the presence of limestone fragments, this clay most probably belongs to the underlying Devyatiny series, and, apparently, was erroneously included by V.P. Barkhatova in the Kayrocheysk subseries, especially since the clay was observed by her

only in one borehole. Hence, it is more correct to consider the Kayrocheysk subseries of V.P. Barkhatova as being composed of dolomitized and silicified limestone with a conglomeratic texture. *Choristites myatschkovens* Fred. et *Choristes priscus* Eichw. are present in the organic remains.

In the bauxite-bearing zone the rocks of the Kashira unit, which corresponds to the Kayrocheysk subseries, are characterized by the remains (collected by us) of these foraminifera: *Pseudostaffella* ex gr. *ozawai* (Lee et Chen), *Ps. gorskyi* (Dutk), *Ps. cf. subquadrata* Crot. et Leb., *Ps. kremisi* Raus., *Ps. aff. confusa* (Lee et Chen), *Ps. sp.*, *Bradyina* sp., *Ozawainella* sp., *Eofusulina tringula* (?) Raus et Bel., *Endothyra* sp., *Fusiella* sp., *Textularia* sp., *Globivalvulina* sp. and *Tubertina* sp. Here also occur the remains of the algae *Beresella* sp., spines of sea urchins and fragments of crinoids.

From this same unit in the Denislavsk depression we collected these brachiopods: *Brachithyrina strangwaysi* Vern., *Samarophoria* sp. indet., *C. aff. crumenia* Mart. and *Spirifer* (Choristites) sp. indet. The rocks of the Kashira unit are light gray, clayey, laminated limestone with a psammitic texture and a thickness of 10 to 15 meters.

Above, one observes deposits of the Karel'sk subseries, which corresponds to the lower half of the Podol'sk unit and, perhaps, to the upper parts of the Kashira unit. These rocks are composed of three diverse limestones (from the base): 1) coarsely fragmental and organic limestone, overcrowded with brachiopods, foraminifera and bryozoa, 2) reef-like limestone with the bryozoa *Fenestella veneris* Eichw., and 3) limestone of an aphanitic texture with rare faunal remains. In the south of the territory under consideration the Karel'sk subseries contains the remains of this rich fauna: *Choristites myatschkovens* Fred., *Ch. mosquensis* Fisch., *Ch. ex gr. priscus* Eichw., *Spirifer regulatus* Fred., *Brachithyrina strangwaysi* Vern., *Chonetes carbonifera* Keys., *Productus* (*Dycyclostos*) *inflatifomis* Ivan., *Staffella sphaeroidea* Ehrenb. and *Fusulina* cf. *ozawai* Raus et Bel.

Many of the enumerated forms are also present in deposits of the Podol'sk unit, revealed by many boreholes within the Denislavsk depression. Here we collected the following foraminifera that are characteristic of the Podol'sk unit of the near-Moscow basin (identified by K.V. Miklukho-Maklay): *Ozawainella neomosquensis* Ras., *Oz. cf. paratingi* Manut, *Oz. sp.*, *Oz. aff. lörentheyi* Sosn., *Pseudostaffella sphaerica* (Ehrenb.), *Ps. khotunensis* Raus., *Parastaffella* sp., *Endothyra rzevica* Reitl., *En. sp.*, *Glomospira* sp.,

Tubertina bulbacea Gall. et Harl., Semiovella sp., Bradyina aff. pseudonautiliformis Reitl., Br. minima Reitl., Glimacammina sp., Textularia sp., Globivalvulina sp. and Tubertina sp. These brachiopods are present here: Marginifera timanica Tschern., Dictyo-clustus inflatiformis Jan., Krotovia sp., Brachythyria strangwaysi Vern., Samaroechia sp. and others.

The overall thickness of the Podol'sk unit in our area undergoes negligible change and is usually fixed at 17 to 25 meters. We did not succeed in recognizing in the bauxite-bearing zone the Sondol'sk subseries, which corresponds to the upper part of the Podol'sk unit.

Carbonate rocks with organic remains (principally foraminifera), characteristic of the Myachkov unit of the Moscow syncline, top the section of the middle Carboniferous on the eastern slope of the Baltic shield. Within the Denislavsk depression these rocks are limestone, dolomite and marl, with a general maximum thickness of 20 meters. Limestone with layers of marl predominate; this limestone is generally very marly itself, having a fine-grained, finely crystalline texture and a light gray color with greenish hues. Considerably more rare dense, light gray dolomite is also present.

In the rocks enumerated we collected the following forms: Fusulinella (?) sp., Endothyra sp., Glomospira sp., Fusulina cf. cylindrica Fisch., Ozawainella cf. angulata Raus., Oz. sp., Oz. cf. mosquensis Raus., Parastaffella aff. preobrajenskyi (Duk.), P. sp., Schubertella sp., Bradyina sp., Tubertina sp. and Cribrostomum sp.

The Zinovsk subseries in the classification of V.P. Barkhatova [4] corresponds to the Myachkov unit in the southern part of the territory considered in this paper. Natural exposures of the rocks of this subseries are present at a number of places along the upper reaches of the Onega River. Here the Zinovsk subseries is composed of yellow-gray, fine-grained, finely crystalline, dolomitized limestone. In various areas, bands of organic rubbly limestone is present with a rich fauna. The Zinovsk subseries is characterized by this complex of organic remains: Choristites ex gr. priscus, Ch. mosquensis Fisch., Ch. jigulensis Stuck., Ch. globulosus Ivan. var. nov., Brachythyria rectangula Kut., Br. strangwaysi Vern., Spirifer regulatus Fred., Productus (Dictyoclostus) ex gr. donesianus Lich., Pr. (Dictyoclostus) inflatiformis Ivan., Pr. (Lino-productus) ex gr. cora d'Orb., Fusulinella pulchra Raus. et Bel. and Staffella angulata Col.

In the middle course of the Onega River

(in the bauxite-bearing zone), as already mentioned, the Onega series combines the Kashira, Podol'sk and Myachkov units of the unified classification, and is represented by a relatively thick (up to 70 meters) stratum of carbonate rocks with organic remains characteristic of the middle Carboniferous of the Moscow syncline.

Besides the forms already cited, from the brachiopods in these deposits we collected: Spirifer (Choristites) ex gr. sowerbyi Fisch., Neophrycodothyris asiatica Chao, Choristites trauscholdi Stuck., Ch. sp. No. 1, Ch. globulosus Ivan., Ch. cf. dilatatus Fisch., Ch. cf. jigulensis Stuck., Ch. priscus Eichw., Camaroecchia sp., C. aff. crumena Eichw., Martinia sp., Marginifera cf. schellwieni Tschern., M. cf. uralica Fisch., M. carnio-lica Schellw., Productus (Echinocondus) neopunctatus Lich., Pr. (Dictyoclostus) inflatiformis Ivan., Pr. kaschirensis Ivan., Pr. (Marginihus) cf. timanensis Lich., Pr. (Dictyoclostus) ex gr. donesianus Lich., Conocardium sp., Rhipidomella michilina L'Ev. and Athyris sp. The following additional foraminifera may be noted: Fusulinella sp. cf. bocki Moell., F. bocki Moell., Quasifusulina (?) sp., Fusulina sp. cf. subpulchra Putrja, Moscoviella sp., Schubertella sp., Climacammina sp. and Cribrostomum sp.

These foraminiferal forms are characteristic of the upper parts of the middle Carboniferous; below these rocks are Profusulinella sp., Fusulina ex gr. praecursus Raus., Bradyina cf. nautiliformis Moell. and Tetraxis sp.; in the very lowest parts of the Onega series occur Parastaffella ex gr. pseudospheroidea (Duk.), Endothyra sp., Globivalvulina sp., Bradyina cf. samarica Reitl., Monotaxis sp. and Estaffella sp.

Within the Iksa depression, the following types of limestone are clearly distinguished by the lithologic composition of the carbonate stratum of the Onega series (from the top downwards):

1. Almost white, fine-grained, finely crystalline (saccharoidal), finely porous, farinaceous limestone of medium or feeble strength, with thin layers of dolomitized limestone, dolomite and rare impressions of poorly-preserved brachiopods;
2. Yellow-white, very porous, commonly spongy, vesicular (size of open vesicles 5 to 15 mm), finely crystalline limestone having a loose texture, with an abundant but poorly-preserved fauna. Separate layers of a denser type in this same limestone contain well-preserved remains of brachiopods and corals.

3. Organic rubble, light gray, very porous limestone;

4. Coarsely crystalline, vesicular, light gray limestone of an angular texture without noticeable organic remains;

5. Brecciated, gray limestone;

6. Cryptocrystalline, yellowish gray, very dense, rigid limestone having an aphanitic texture, with rare remains of brachiopods.

In the Konosha borehole section, deposits of the middle Carboniferous, revealed in the interval between 352 and 489 meters (137 m), are not distinguishable with the exception of the identification of the Vereya unit (460 to 489 meters). They are represented in the upper part of the section (352 to 442 meters) by light gray and white, strongly silicified and gypsiferous limestone, and below this by brownish red clay and lilac and yellowish pink marl (442 to 470 meters); white and light gray dolomitized, in places gypsiferous limestone occurs at the very base of the stratum (470 to 489 meters).

With respect to both lithologic composition and the fossil fauna, the middle Carboniferous deposits are composed of a rather monotonous complex of rocks in the area of the deep Nyandoma borehole. Here, also they are not differentiated. The middle Carboniferous is penetrated at a depth of 251.80 to 305.25 meters (53.45 meters) in the Nyandoma borehole. A band of fine-grained, finely crystalline, strongly dolomitized, siliceous, dark gray limestone, with a thickness of 5 meters, is detected at the very base of the section. Beds of interstratified, dense, dolomitized limestone and organic rubbly limestone with foraminiferal remains are present throughout the entire remainder of the section. In these limestones, the following fauna are present: *Bradyina nautiliformis* Moll., *Climacammina* sp., *Endothyra* ex gr. *baumani* Phill., *Fusella* cf. *typica* Lee et Chen., *F. elegans* Raus. et Bel., *Staffella angulata* Col., *St. cf. moelleri* Ozawa, *Productus* (*Avonia*) *echiniformis* Chao., *Pr. (Echinoconchus) punctatus* Mart., *Pr. (Dictyoclostus) inflatiformis* Ivan., *Pr. (Marginifera) timanica* Tschern., *Spiriferella* sp., *Brachythyra restangula* Kut. and *Choristites myatschkovens* Fred.

In the borehole sections of the Shirbozersk sequence, as in the other prospecting structural boreholes, the Onega series is represented principally by limestone of the above-described varieties. The general thickness of the series nowhere exceeds 70 meters.

UPPER CARBONIFEROUS (C₃)

The boundary between the upper and middle divisions of the Carboniferous system in the area considered is assumed to lie along the base of the brecciated limestone, with which

the carbonate stratum of the upper Carboniferous begins. The stratigraphic position of this boundary is substantiated paleontologically. There are widely developed in the lowest parts of the carbonate bed, coarsely-ribbed choristids of the Samarian type, various products, especially of such species as *Lino-productus*, *Dictyoclostus*, *Echinoconchus* and *Marginifera*, as well as highly-organized foraminifera (*Pseudofusulina*, *Schwagerina* and others). The boundary between the Permian and upper Carboniferous is less clear. At present, it is placed along the base of the Borosvid series and this latter series is assigned to the lower Permian.

Upper Carboniferous deposits occupy the central part of the territory in question. They stretch northeasterly in the form of a belt with a width of 3 to 50 kilometers (in the south up to 100 kilometers). Natural outcrops of these rocks are present in the upper course of the Onega. The most representative exposures are between the source of the Onega and the village of Semenovskoy, as well as along the Chur'yega (above the village of Gar'), Voloshka and Svida Rivers. Upper Carboniferous deposits are revealed also in their full thickness in a large number of the holes drilled along the eastern slope of the Baltic shield. It has also been established by prospecting boreholes for bauxite that upper Carboniferous formations are entirely absent within the Ikse depression.

V.P. Barkhatova [4] subdivides the carbonate beds of the upper Carboniferous in the southern part of the area into the following four series (from the base upwards): Chur'yega, Akulov, Nadporozh and Borosvid. In consequence of the typical lower Permian complex of foraminifera which it contains, this latter series is transferred to the Permian system, as has already been indicated above, and characterizes the base of this system.

In petrographic composition, the upper Carboniferous is represented almost without exception by carbonate rocks, whose general thickness reaches 100 meters in the south and not more than 60 meters within the bauxite-bearing zone.

The brachiopod fauna collected by us indicates the presence also of the Chur'yega and Akulov series of V.P. Barkhatova's scheme in the area of the middle course of the Onega River. Here one finds: *Lino-productus* ex gr. *cora* d'Orb., *L. cora* d'Orb., *L. neffedievi* Ivan., *Productus* (*Buxtonia*) *subpunctatus* Nik., *Pr. kaschiriensis* Ivan., *Pr. ex gr. donetsianus* Lich., *Spirifer strangwaysi* Vern., *Sp. tegulatus* Fred., *Marginifera* cf. *invaluta* Fisch., *Squamularia* cf. *lincata* Martin.

The limestones are usually very argillaceous, foliated, fine-grained, finely crystalline, greenish gray or yellowish white, with layers of organic and finely fragmental limestone and marl in places, having a thickness of 0.3 to 1.3 meters.

Not dwelling on the lithologic and faunal character of the series distinguished by V.P. Barkhatova in the southern part of the territory considered, we will note that one meets there the same kind of limestone and a brachiopod faunal complex close to that cited above.

According to V.P. Barkhatova [3], the upper Carboniferous is represented by all three series in the Nyandoma borehole section (depth of from 160.8 to 251.8 meters). The Chur'yega series is composed of fine-grained, clayey limestone of a violet and a reddish brown color; its thickness is 12 meters; it is characteristic that foraminifera are almost entirely absent here. The Akulov series, with a thickness of about 28 meters, is represented by a stratum of interbedded, organic rubbly and foraminiferous limestones with layers of marl, dolomitized limestone and dolomites, with the remains of brachiopod and foraminiferal forms characteristic of this series. The Nadporozh series is expressed by a stratum of interbedded limestone, dolomitized limestone and dolomite containing foraminifera; its thickness is 50 meters.

In the Konosha borehole section, the upper Carboniferous is revealed in the interval between 268 and 352 meters (84 m), and is composed mainly of light gray dolomitized limestone of a fine-grained and finely crystalline texture, in places very gypsiferous. A pinkish gray dolomitic marl occurs at the base of the stratum.

In conclusion it may be noted that the lowest members of the carbonate beds of the upper Carboniferous are usually represented over a considerable area by chemically pure limestone which is a high-grade fluxing material (Shvakinsk deposit and others).

SHORT PALEOGEOGRAPHY OF THE CARBONIFEROUS

Along the whole of the eastern slope of the Baltic shield, we do not find any signs of marine conditions of sedimentation throughout almost all the lower Carboniferous epoch, with an exception during a short segment of Devyatin time. Beginning from the end of the Tournaisian age (Kizelovsk time) and throughout almost all the Visean age, the area in question was a coastal plain, swampy in places, covered by a moisture-loving vegetation, with small, scattered shallow lakes.

During this epoch, mainly in coal-bearing time, the conversion of plant remains into lignite was taking place on the western side of the near-Moscow basin. In the Tikhvin and Onega areas, however, on the northwestern extension of the basin, free hydroxides of aluminum and iron were being concentrated, together with finely dispersed clastic material (and at times also without), in low-lying parts of the topography (in the river valleys of the Tikhvin area and the lacustrine swampy hollows of the Onega area) to form commercial deposits of bauxite and iron ore (Onega area).

During clearly Polyansk time in the southern half of the area considered, there may have existed a shallow freshwater lagoon in the process of evaporation, in which, side by side with clay, carbonate rocks were also periodically deposited in the form of sandy marl, dolomite and strongly dolomitized and sandy limestone with a psammitic structure.

The Tagazhema series in full measure reflects the lithologic composition of this lagoon. In separate localities near the shoreline of the lagoon, favorable physical and chemical conditions were created for the formation of iron pisoliths that are disseminated in the clay or concentrated into separate, extremely thin layers. A marine regime of sedimentation was established for a certain, very short-lived time only towards the end of the lower Carboniferous epoch in the territory situated to the south of the Vetreny zone, the evidence for this being provided by the development of a small thickness of Devyatin limestone (5 to 15 meters). On the northern slope of the Vetreny zone a marine regime of sedimentation, although under the most unstable conditions, nevertheless continued for a somewhat longer period, already in post-Devyatin time, which resulted in the accumulation of the unusual terrigenous carbonate sediments that are distinguished as the Biryuchevsk series.

On the Devyatin limestone in the southern half of the territory, signs of subaerial weathering are well expressed, whereas the deposits of the Biryuchevsk series conformably overlie them without any noticeable signs of a discontinuity north of the Vetreny zone. These facts testify to the retreat of the sea during post-Devyatin time in the south and to the preservation of the littoral-marine conditions of sedimentation in the north of our area. A new marine transgression took place at the beginning of Kashira time (Moscow stage), the marine regime of sedimentation established for the whole territory of the eastern slope of the Baltic shield thereby continuing to exist up to the end of the Carboniferous Period. In the southwestern part of the area, this regime apparently persisted even at the beginning of the lower Permian

(Borosvid time), although towards this time the general regression of the sea was clearly beginning to take place in a southwesterly direction. The marine conditions of sedimentation, however, were not permanent, and they changed especially abruptly between the middle and upper Carboniferous and again between the upper Carboniferous and lower Permian. This found a more or less clear expression both in the noticeable change in the composition of the whole faunal complex, and also in the morphologic features of the fauna (the appearance of coarsely-ribbed choristitids at the beginning of the upper Carboniferous, the exceptional development of sutured genera at the beginning of the lower Permian, etc.).

The sea retreated from almost the whole area only at the end of the lower Permian and the extensive lagoon, which existed outside the territory under consideration, was preserved solely in the southeast.

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THE EFFECT OF WATER-SOLUBLE SALTS IN CLAYS ON ELECTRON PHOTOMICROGRAPHS OF CLAY MINERALS¹

by

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Electron-microscopic study of dispersed clay minerals of the fraction smaller than 0.001 millimeter is the only known means of obtaining data on the form and size of such particles.

In recent years, the application of the electron-microscopic method in the study of the morphology of clay mineral particles has become increasingly extensive [2, 3, 4, 5, 10, 11]. This interest is due to the fact that the size and especially the form of such particles vary depending on the mineral constitution of the clay. For that reason, the electron microscope is a powerful means of identification of clay minerals from the peculiar forms of their particles and, what is most important, of determining the conditions of formation of clay minerals by the size, shape, and the state of preservation of crystallographic outlines in the particles [3, 4, 5].

Experience has shown, however, that a number of outside factors should be taken into account, in evaluating electron photomicrographs.

It has been noted, for example, in the study of various clay rocks that the definite and typical pattern of mineral particles is occasionally replaced in electron-microscopic preparations, by specks, knots, and films, often in a bizarre pattern (Figs. 1-a, 2-a, 3-a). It should be noted that similar formations have been observed by other students who either misinterpreted them ([2], Figs. 4 and 10) or left them undeciphered ([9], Fig. 9).

Because of the fact such formations not only do not reflect the true composition of the clay minerals but often imitate quite different varieties, we experimented to determine the nature of these minerals.

As a rule, the assorted specks, knots, and films are present in electron-microscopic preparations of unstable suspensions, although they occur occasionally in relatively stable ones. It is known from colloid chemistry that one cause of the instability of clay suspensions is the coagulation of clay particles affected by electrolytes. The latter originate in the solution of salts present in a number of clay rocks of a suspension. A qualitative reaction for the $\text{Cl}^-(\text{AgNO}_3)$ and $\text{SO}_4^{2-}(\text{BaCl}_2)$ ions always reveals their presence.

It is known from our practice of obtaining electron-microscopic preparations of clay minerals [2] that in qualitative preparations unstable suspensions and electrolytes are elutriated by decanting, until a stable state has been attained. However, our own experience of many years has shown that occasionally the transition of suspensions to a stable state is achieved considerably before the entire elimination of electrolytes. In that event, the concentration of electrolytes is below the coagulation point. A further elutriation of such suspensions does not give satisfactory results, as a rule.

In order fully to eliminate electrolytes from suspensions, without a loss of clay material, we have worked out, at the Geological Institute, Academy of Sciences, U.S.S.R., a simple and reliable method of elutriation of clay rocks, applicable at any concentration of electrolytes in them. In this process, suspensions are evaporated at 80°C, in porcelain crucibles, until a fairly dense clay crust is formed at the bottom. This crust is covered by distilled water which is decanted each day for a period of time (depending on the concentration of salts). It is of interest that the crust, generally, is but slightly macerated, which precludes the loss of clay. At the same time, the crust structure does not interfere with the passage of soluble substances into solution, as seen in microphotographs. In this way, particles of clay minerals, typical of a given sample (Figs. 1-b, 2-b, 3-b, 4-b) are obtained instead of salt separates (Figs. 1-a, 2-a, 3-a, 4-a).

¹Vliyaniye vodnorastvorimykh soley v glinakh na kharakter elektronnykh mikrofotografii glinistykh mineralov.

Table 1
Spectrum Analysis of Saline Samples of Clay rocks

Elements	Montmorillonite with addition of kaolinite. White silt. Sample 110, south slope of the Ulu-Tau Mountain; Cr ₂ 2				Isometric, tabular hydromica with an addition of kaolinite. The clay is greenish gray. Sample 59-1, Akzhir River; Ni ₁ 42				Kaolinite with an addition of elongated, tabular hydromica. Clay white, sandy. Sample 78-3, Nizhny Ashut River; Fe ₃ 8a				Montmorillonite with a Mg-silicate mineral. Clay, pink; sample 244; Arystrydy ₂ River; Fe ₁				Kaolinite. Clay white, brittle. Sample 93, Chistopol'; C ₁ 2s tal				Monothermite. Lignite clay. Sample 154, south slope of Ulu-Tau; Cr ₂ 2			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Mn	3	8			4	10		2	1	6	10	8	2	9	10	3	2	5	10	2	4	8	3	3
Ng	10	10	6	4	10	10	9	4	10	6	6	6	3	10	8	5	10	4	10	2	8	10	8	8
Si	8	10	8	4	9	10	8	6	10	6	10	3	10	10	8	5	4	3	10	4	8	10	8	3
Fe	10	10	7	3	10	10	9	3	10	3	10	3	10	10	3	2	10	5	10	3	10	10	8	2
Al	2	2	4	4	4	6	3	3	2	2	2	2	3	3	3	4	4	4	3	1	3	3	3	—
V	5	3	3	—	4	6	4	4	5	5	5	—	5	2	2	—	2	7	4	3	6	5	4	—
Ti	3	2	4	3	3	3	3	0	2	2	1	4	3	3	3	8	2	3	3	4	4	3	3	2
Cr	2	1	—	8	3	3	—	0	10	4	—	4	1	3	2	2	2	2	2	9	3	1	2	40
Na	1	3	1	2	3	3	2	4	4	4	2	4	3	3	3	2	3	3	3	3	3	2	2	2
Ni	3	3	1	—	2	2	1	8	10	4	4	4	6	6	4	—	8	5	4	4	6	4	1	6
Zr	7	6	5	2	4	4	4	3	4	1	1	4	3	2	2	4	4	4	4	4	1	1	—	—
Ca	2	2	—	1	3	3	1	3	4	2	2	2	2	2	4	—	4	4	4	3	4	1	3	—
Sr	2	2	—																					
Cr																								

It must be noted, however, that the complete separation of clay rocks and salts takes a fairly long time.

The method of suspension elutriation on membrane filters with a water jet or a vacuum pump can be used to speed up the separation of clay rocks. V.I. Appolonov [1] offers a valuable suggestion in recommending the elutriation of a previously isolated fraction, smaller than 0.01 millimeter, because the presence of a coarser fraction considerably lengthens the salt extraction process. He also notes that elutriated suspensions out of which qualitative preparations are obtained become unsuitable for that purpose, in time. We have succeeded in explaining this by the fact that, with the readily soluble salts eliminated, the less soluble salts again saturate the suspension, in time, to such an extent as to make it impossible to obtain qualitative preparations. For that reason, V.I. Appolonov recommends that the preparations be obtained right after the separation of a fraction smaller than 0.001 millimeter from the elutriated clay rock.

The necessity for complete elutriation of clay rocks from soluble salts is related to the specific features of our method of obtaining such preparations [2], wherein the suspension drops are allowed to dry out on the slide. In that event, salts present in the solution are precipitated in a film which veils the clay mineral particles, and promotes their aggregation. As a result, aggregates considerably larger than one micron are observed along with the new formations of salts. This indicates their formation during the preparation process, because under elutriation conditions (in 24 hours), they should have been removed from the suspension.

It is to be noted that the Scholler and Co. electrotechnical plant at Frankfurt-on-Main (German Federated Republic) manufactures an "ultrasonic fog-maker" (Ultraschnellneber, type USMG) which makes it possible to obtain uniformly high quality preparations. The principle of this method is that a drop of suspension, acted upon supersonically in a special cylinder, becomes a fog into which a filmed screen is introduced. The fog drops so obtained measure about one micron, i.e., they are of the same order of magnitude as the clay mineral particles. Distributed practically one particle to a drop, and settling on the film, one by one, these particles do not coagulate, and an even distribution of material is achieved. In our opinion, this method is effective and deserves a general application.

Having considered the effect of soluble salts on the quality of electron-microphotographs of clay minerals, we shall pause

briefly for the problem of relative mobility of various elements in elutriation of clay and for the chemical nature of salt extractions.

For that purpose, N.V. Lizunov spectrographically analysed in the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Academy of Sciences, U.S.S.R. (IGEM), a number of saline samples, at different stages of the salt elimination, in obtaining the characteristics of initial (sample I), intermediate (sample II), and terminal (sample III) elutriation products and of water extracts at an intermediate elutriation stage (sample IV).

In Table 1, which lists the results obtained, sample I represents the original material; sample II, the original material washed on a membrane filter with 500 milliliters distilled water (incompletely washed of salts); sample III, original material completely washed of salts; and sample IV, dry residue of evaporated filtrate.

The Table shows that of cations forming the most common salts, Na passes into filtrate the fastest and most completely. It is missing in sample III; on the other hand, its concentration in the dry residue is the highest of all other elements. Mg and Ca also have a high filtrate concentration; it is significant that their maximum concentration takes place in filtrates of kaolinitic clays (samples 78-3 and 93).

Considering the low exchange capacity of kaolinitic clays, it can be assumed that Mg and Ca which pass into filtrate do so as components of the salt complex and are not connected with the mineral lattice; this is also corroborated by the fact that the filtrate concentration of Mg in a magnesium-montmorillonite clay (sample 244) is much lower than in the clay matrix. As seen from the Table, elements which are principal participants in the structure of a mineral lattice (Si and Al) also pass into filtrate, although in relatively small amounts. Such a possibility, under certain conditions, was also indicated by V.I. Lebedev [6]. A similar behavior is displayed by Fe.

A number of elements, such as Ti and V, are not present in filtrates, being bound to other mineral formations; for example, Ti probably enters the composition of rutile.

E.S. Zalmanzon, of the Geological Institute, U.S.S.R. Acad. of Sciences, studied the content of Cl^- , SO_4^{2-} , and HCO_3^- in water extracts of the same samples (Table 2). An analysis of the results so obtained, and their correlation with electron microphotographs of saline clays, show a direct relation of the amount of Cl^- in water extract with the density of salt films on photomicrographs (Fig. 1-a, 2-a, 3-a).

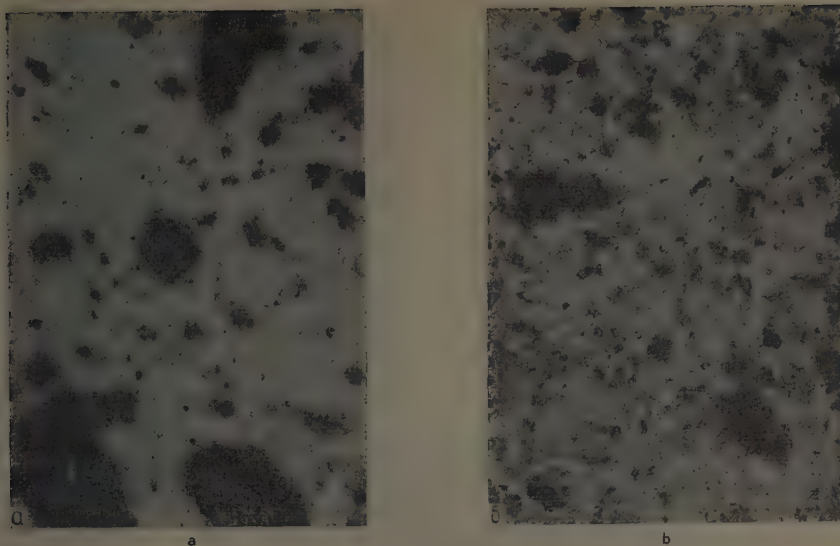


FIGURE 1. Montmorillonite with an addition of kaolinite.

Electron photomicrograph of sample 110, magnified 9,000X; a -- before elutriation;
b -- after elutriation.

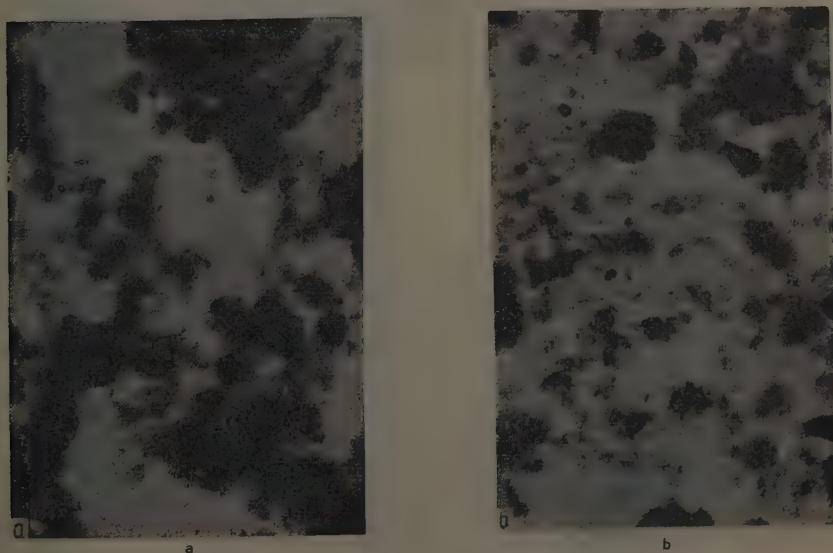
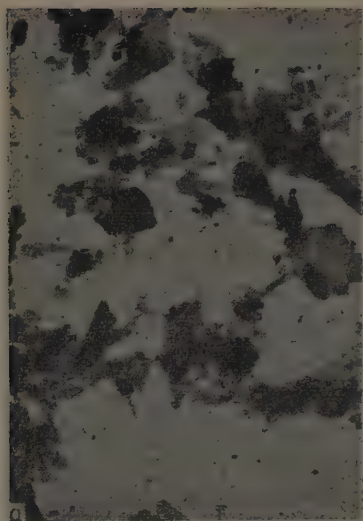
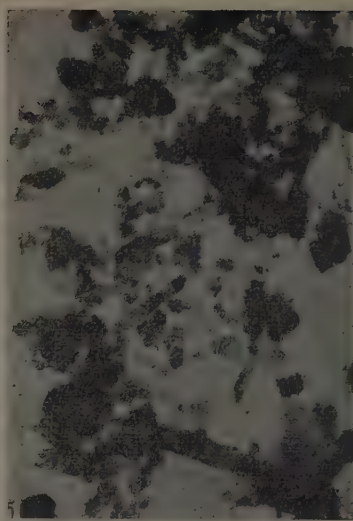


FIGURE 2. Isometric, tabular hydromica with kaolinite.

Electron photomicrograph of sample 59-1, magnified 9,000X; a -- before elutriation;
b -- after elutriation of salts.



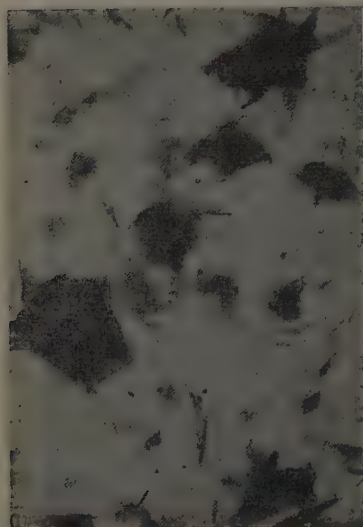
a



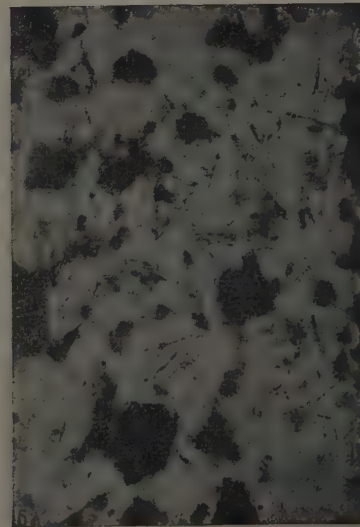
b

FIGURE 3. Kaolinite with elongate, tabular hydromica.

Electron photomicrograph of sample 78-3, magnified 9,000X; a -- before elutriation; b -- after elutriation of salts.



a



b

FIGURE 4. Montmorillonite with a Mg-silicate mineral.

Electron photomicrograph of sample 244, magnified 9,000X; a -- before elutriation; b -- after elutriation of salts.

Table 2

Content of Cl' , SO_4'' , and HCO_3' ions, in milligrams to 500 milliliters of filtrate

Samples	Anions, in mg to 500 ml		
	Cl'	SO_4''	HCO_3'
110	39.85	6.57	0.0003
59-1	16.03	13.96	0.0033
78-3	17.12	6.97	0.0004
244	3.16	47.99	0.0002
93	22.42	5.38	0.0004
154	Not determined	14.34	0.0003

Table 2 shows that the amount of HCO_3' ions in the clays under study is very small, and that these clays, with the exception of sample 59-1, are practically free of carbonate.

Salt films are considerably more numerous on the microphotograph of sample 59-1 (Fig. 2-a) than on those of sample 78-3 (Fig. 3-a), although the quantitative content of ion Cl' in their salt extractions is almost the same. As seen from Table 2, this can be explained by the higher amount of carbonates in sample 59-1; consequently, the effect of carbonates is similar to that of chlorides.

In order to determine the morphologic characteristics of crystals of the most common

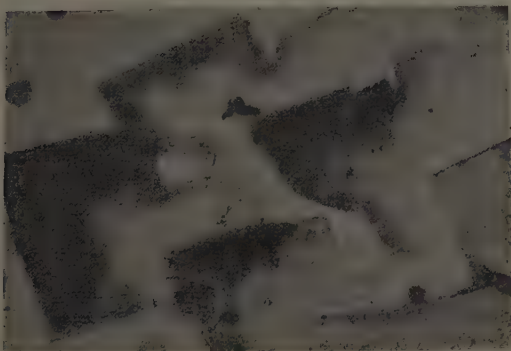


FIGURE 5. 0.1 N solution of NaCl .
Electron photomicrograph, 9,000X.



FIGURE 6. 0.1 N solution of K_2CO_3 .
Electron photomicrograph, 9,000X.

salts, for the purpose of using the data so obtained in deciphering the composition of salts on photomicrographs of saline clays, we studied 0.1 N water solution of chemically pure chlorides, sulfates, and carbonates of Na, K, Mg, and Ca.² Each salt has yielded a specific crystal form (Figs. 5 and 6), similar to those used in microchemical analysis [7]. We note that we have obtained for CaCO_3 a photomicrograph similar to that cited by F.V. Chukhrov [8].

A comparison of photomicrographs of pure salts with new formations on the photographs of saline clays has shown that identical pictures are very rare. For the time being, we have observed on the photographs of saline clays only the crystals of gypsum, CaSO_4 , and soda, Na_2CO_3 (Fig. 4-a), and also some more complex chemical compounds similar to those obtained by L.I. Zemlyanova in her thesis work on the application of electron-microscopy to microchemical analysis. In all probability, the rarity of crystallographic forms of certain composition of salts is related, as seen from Table 2, to the complex multicomponent composition of salts present in the clays, which mutually prevent the normal development of conditions favorable for the crystallization of certain compounds.

In our study of pure salts, we have noted that dense films similar to those illustrated in photomicrographs of sample 110 (Fig. 1-a) and sample 59-1 (Fig. 2-a), were obtained for all chlorides investigated (with the exception of KCl), as well as for Na sulfate and the carbonates of Mg and Ca (Fig. 5). Other sulfates and carbonates of Na and K produced well-formed crystals on preparations without films (Fig. 6). A similar phenomenon was observed for sample 244 which contained a definite increase in the SO_4^{2-} ion content, in the water extract. Films are absent on the micrographs of this sample (Fig. 4-a); instead there are conspicuous semi-transparent spindle-shaped new formations of Na_2CO_3 , sharply different from acicular crystals of the Mg-silicate mineral, appearing after the elutriation (Fig. 4-b).

Thus, our study has shown that the true morphologic character of clay minerals is revealed in electron photomicrographs only in the absence or after the elimination of soluble salts from clay rocks. Otherwise, various new formations which originate in the preparations themselves during their processing may be taken for clay mineral particles. The elutriation of salts should be done without any loss of clay material. It has been established that different salt groups

affect the electron photomicrographs in different ways. Chlorides and carbonates exercise the most effect, with halite (NaCl) the most effective; spectrographic analyses have shown that the latter's elimination must be complete in order to obtain quality electron-photomicrographs.

Considering the comparatively long time required to eliminate soluble salts from clays, the value of new and more efficient methods of preparation, with the help of "ultrasonic fog makers" is obvious.

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10. CLAYS AND CLAY MINERALS: National

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PRINCIPLES OF A RATIONAL CLASSIFICATION OF METAMORPHOSED CARBONATE ROCKS¹

by

P. P. Smolin

A unified classification of metamorphosed carbonate rocks is proposed, based on qualitative mineral composition, with emphasis on the ratio of the carbonate component minerals and on that of the carbonate component and silica. Three principal groups of rocks are differentiated by the last criterion: carbonates proper — marble — containing less than 10% metamorphosed silicates; silicates proper — hornfels and skarn — with less than 10% carbonate minerals; intermediate — calciphyres. In addition, our classification includes a petrologically important group of brucite marbles whose isolated position in the present classification is not justified petrographically, as demonstrated by the author's study.

* * * * *

INTRODUCTION

A number of detailed classifications have been worked out for sedimentary and igneous rocks, while only the old classification of hornfels by V.M. Goldschmidt [20] and of crystalline schist by V. Grubenmann [22] are extant for metamorphic rocks. Meta-carbonates, despite their large number, are known only by unsystematic names, commonly petrographically indeterminable; as a consequence, rocks of similar composition and origin are usually known by different names. The names of essentially meta-carbonate rocks often do not give any hint of their main feature — the carbonate nature of their component minerals. This leads to the lack of definite characteristics for entire complexes of carbonate rocks, which, in turn, hampers exploration for minerals, because a magnesian or a calcareous composition of meta-carbonates affects the concentration in them of both sedimentary and endogenetic minerals (such as magnesian borates or datolite). Such an unsatisfactory situation with regard to the nomenclature of meta-carbonates calls for a single classification which, while preserving as far as possible the old nomenclature, will render it more petrographically precise.

I. THE PRESENT NOMENCLATURE AND THE OBJECT AND PRINCIPLES OF CLASSIFICATION

It is known that large bodies of carbonate rocks occur both in a pure state and with added terrigenous material. As a result, metamorphic silicates originate during the metamorphism of such rocks; similar results are achieved by the addition of igneous material to pure carbonate rocks. For that reason, a comprehensive classification of meta-carbonates should encompass the entire range of metamorphic rocks — from pure carbonates to pure silicates. It is best not to include ore-vein carbonate bodies in such a classification because they belong to a special ore-bearing group. First among rocks to be considered in the present classification are metamorphic equivalents of limestone, dolomite, dolomitic limestone, and marly and siliceous varieties of these rocks. Inasmuch as magnesite occasionally makes up sizable bodies in meta-carbonates, they, too, should be included among the rocks to be considered.

Let us review briefly the present terms for these rocks.

Marble is the name long known for meta-carbonate rocks;² it implies a metamorphic

¹Ob osnovakh ratsional'noy klassifikatsii metamorfizovannykh karbonatnykh porod.

²There is also a technical definition of marble as a fine- to medium-grained carbonate rock capable of

recrystallization but does not convey a clear idea of the rock composition: there are, for example, regionally metamorphic and contact metamorphic marbles.

At the same time, the term dolomitic marble is occasionally used, obviously to contrast it with the plain marble which thereby is defined by its calcareous composition and becomes a synonym for crystalline limestone (G. Rosenbush, [11]; V.I. Luchitskiy, [8]). In one of the latest petrographic manuals (H. Williams, F.J. Turner, and C.M. Gilbert, [1]), the term marble is applied to metamorphic rocks consisting of either calcite or dolomite.

On the other hand, as a result of the work of A. Harker [23], such terms as tremolite marble and forsterite marble appeared; these terms, however, only emphasize the presence of certain metamorphic silicates and utterly neglect the nature of the carbonates; conversely, rocks carrying a considerable amount of silicates are often called dolomitic marbles, to mean that the carbonate component of the original rock was represented chiefly by dolomite (A.A. Marakushev, [9]). In the latter type, designated as dolomitic marble, there also are rocks without any dolomite and containing only magnesian silicates (at times definitely predominant) and calcite; such a practice is hardly expedient.

Names predazzite and pentacite have long been known for an interesting group of meta-carbonates with brucite for a rock-forming mineral along with carbonates. These rocks were first discovered at Predazzo, Tyrol, in 1845. A. Petzoldt [27], who determined their composition, believed that they were made up of a single mineral, $2 \text{CaCO}_3 \cdot \text{Mg}(\text{OH})_2$, which he named predazzite. Later on, in 1851, J. Roth [28, 29] discovered another "mineral species" of composition $\text{CaCO}_3 \cdot \text{Mg}(\text{OH})_2$, which was named pentacite after the well-known Alpine geologist Marcari Pentacite.

A microscopic study revealed that both "minerals" were brucite-calcite rocks.

A stamp of authority was given to these names by A. Harker [23] who suggested that the name pentacite be associated with a 1:1 molecular ratio of calcite and brucite (36.8% brucite and 63.2% calcite, by weight), while the varieties with calcite predominant over brucite be known as predazzite. Later on,

a collective term brucite marble (T. Watanabe, [31]) appeared, to unite all brucite-carrying carbonate rocks. The Canadian geologists, M.F. Goudge [21] and M.L. Keith [25] call such brucite-carrying rocks brucite limestone, which does not connote either their metamorphic nature or their composition, because there are among them some interesting varieties consisting almost exclusively of dolomite and brucite. Brucite is formed in brucite marbles usually as a pseudomorph on periclase; in those isolated examples where a considerable amount of unreplaced periclase is left behind, the terms periclase marble [23] and periclase predazzite [26] are applied.

Another most interesting and rare meta-carbonate group is represented by cotoite marble [32] which carries, along with calcite, magnesian borate - cotoite ($3 \text{MgO} \cdot \text{B}_2\text{O}_3$).

Added silicate minerals in meta-carbonate rocks are often designated by an adjective; however, a number of special terms are used for these rocks: cippolino is a green banded mica-talc-calcite rock; ophiocalcite is a serpentine-calcite rock; hislopite is a green glauconite-calcite rock, etc. The term cal-ciphyre, originally applied to a calcitic marble with porphyroblasts of granite, pyroxene, and feldspar (A. Brongniart, [17]), has come to mean in Soviet literature carbonate rocks in general, irrespective of composition, provided they have a high content of metamorphic silicates [2]. Because of the indeterminate quantitative boundaries of the mineral content, this term is in competition with such specific names as forsterite marble. In addition, the term skarn limestone is applied to these metamorphic rocks, with the genetic implication of the name commonly not justified.

The essentially silicate contact-metamorphic rocks, including those derived from marly and siliceous carbonate rocks, have long been known as hornfels. Those rocks formed from marly limestone and containing mostly calcite metamorphic minerals, are known as calcareous hornfels (class 5-10 of V.M. Goldschmidt, [20]); similar rocks, formed in the metamorphism of siliceous and marly dolomite with predominant magnesian silicates, are sometimes termed magnesian hornfels (C.E. Tilley, [30]). Of regionally metamorphosed rocks, are calcareous schist (F.J. Turner, [16]) is hornfels of low temperature metamorphic facies. Magnesian crystalline schist is a collective name for ultrabasic metamorphics [1]. Rocks of similar mineral association also occur in regionally metamorphosed carbonate facies enriched in terrigenous additives - assorted talc-carbonate and talc schists, commonly also carrying tremolite.

taking a polish and suitable for sculpture [7]. In this interpretation, marbles would include non-metamorphic carbonate rocks. This technical definition of marble has long since been dropped from petrographic literature.

Thus, the terms hornfels and crystalline schist reflect the structural definition of a rock, the first term being applied most often to contact metamorphic rocks, while the second denotes the regional metamorphics.

The term *skarn* was originally a local name for metamorphic rocks made up of calcareous-ferruginous to calcareous-magnesian-ferruginous silicates in ore deposits of Sweden, and related to limestone (Goldschmidt, [20]). As a result of D.S. Korzhinskiy's work, it has acquired a more definite meaning and is widely applied to metasomatic contact-reaction rocks formed at the contact between aluminosilicate and carbonate rocks. As a result of a detailed study of skarns formed from the addition of silicate material to carbonate rocks, two main groups have been differentiated: calcareous skarn, formed most often in the metamorphism of limestone and carrying an excess of calcareous minerals, and magnesian skarn formed at the expense of dolomite and carrying typical magnesian minerals [6]. Some metamorphics, which are essentially skarn, are called simply rocks, because of their wide distribution throughout regionally metamorphosed bodies (the Aldan Archean), as diopside rocks [10].

D.S. Korzhinskiy [6] proposes the name stratified skarnoids for those rocks which participate in banded members of meta-carbonates, and are close to hornfels, but have been formed as the result of a perceptible change in chemical composition.

In considering meta-carbonates, it is expedient to differentiate first their carbonate (soluble) fraction, as such, including the corresponding oxides and hydroxides (periclase, brucite); and the non-carbonate (insoluble) fraction represented by metamorphic silicates.

This brief review of the terms is sufficient to show that many rock names do not reflect clearly the composition of rock-forming carbonates; this probably is due to the difficulty in the certain identification of carbonates in thin section.³ At the same time, the underscoring of metamorphic silicate additions, as expressed in a number of rock names, is of importance because such minerals characterize the degree of metamorphism.

In selecting the basis for a classification of meta-carbonates, it should be kept in mind, first of all, that rocks quite similar in composition and texture may originate in both the migration of matter in the process of metamorphism, and from the primary features of a rock, with only the most careful study at times revealing unequivocally their true origin. Consequently, the composition criterion should be accepted as the basis for a classification. Inasmuch as a variable addition of terrigenous material is almost always present in carbonate rocks, with the carbonate fraction itself commonly represented by a mixture of carbonates in various proportions, a comprehensive classification should differentiate between certain segments of the rock composition. Sharp genetic boundaries of such segments are impossible; only their conditional boundaries can be established with any degree of certainty. It should be kept in mind that the presence of an excessive number of arbitrary quantitatively differentiated mineralogical rock varieties leads to cumbersome classifications, of little practical use.

Thus a rational classification of meta-carbonate rocks should be built upon a quantitative-mineralogical basis and should reflect first of all the ratios of principal rock-forming minerals (soluble), whose composition is inadequately presented in the current nomenclature. Such a classification should, in addition, reflect the incipient tendencies by emphasizing the typical addition of insoluble metamorphic minerals (indicators of the degree of metamorphism), preserve as far as possible the historically developed terminology, and take into account the genetic criterion.

II. THE PROPOSED CLASSIFICATION

In a classification of metamorphosed carbonate rocks, it is expedient to consider common widely-developed varieties whose soluble fraction is not more magnesian than dolomite (metamorphic analogues of limestone, dolomitic limestone, and dolomite), apart from more magnesian rocks which are less common and which are comparatively little known.

1. Metamorphosed Carbonate Rocks Not More Magnesian Than Dolomite in Their Soluble Fraction

In this group, the main factor which determines the nature of a rock is the amount of silicate added. Accordingly, three groups may be designated: essentially carbonate, essentially silicate, and intermediate silicate-carbonate. Such a classification is partially implied in the present nomenclature. This classification trend only needs to be made

³The distinctive feature of carbonates, such as the form of grains, the number of inclusions, and the character of twinning, are not always present and usually leave some uncertainty. The precise identification from refraction in powdered samples does not give the quantitative ratios of carbonates. A simple and reliable method is a diagnostic coloring of carbonates in polished sections, which unfortunately is not adequately used in the study of meta-carbonate rocks.

more definite by establishing certain arbitrary boundaries. We believe that such a boundary can be represented by a 10% silicate content, which is the standard maximum content of subordinate minerals in rocks. The name marble should be assigned to rocks with less than 10% insoluble minerals; such a name will emphasize the metamorphic recrystallization of rocks and their low metamorphic silicate content. Varieties with less than 10% soluble minerals should be assigned to essentially silicate rocks — hornfels and skarn (also calcareous and magnesian schist). The intermediate group of rocks should be assigned a collective name of calciphyre. This broadening of the original meaning of this term is in some contradiction to its etymology; the necessity of such a broadening is, however, dictated by petrographic experience. Most diversified geologic organizations designate as calciphyres meta-carbonate rocks with a higher silicate content. Beginning with the works of B. Z. Kolenko [4] and D. S. Korzhinskiy [5], this term has become especially popular for rocks containing magnesian minerals, such as forsterite, spinel, etc., rather than calcareous minerals.

1) Marbles

Most typical marbles are carbonate rocks consisting essentially of calcite and dolomite; they also include a special group of brucite marbles.

Brucite marbles are formed usually by thermal metamorphism of dolomite and dolomitic limestone, as a result of so-called total de-dolomitization, a decomposition of dolomite into an aggregate of periclase and calcite, with the subsequent hydration of periclase to brucite. In this process, the chemical composition of the rock is altered in terms of its content of carbon dioxide and water, while the ratios of principal components — magnesia and lime — remain the same. For example, corresponding to pure dolomite is its metamorphic analogue — pentacite, with the molecular ratio $\text{CaO:MgO} = 1:1$ (or 1.39, by weight). But usually, brucite marbles are either close to pentacite or are close to predazzites, somewhat enriched in calcium, as compared with pentacite, and thus correspond to dolomitic limestones in their MgO and CaO content.

Detailed petrographic observations have established that the most common alteration of brucite marble, in retrograde metamorphism, is redolomitization as expressed in reconstruction of dolomite, in a reaction between brucite and calcite. For that reason, pentacite, which consists only of calcite and brucite, is very rare and always contains some dolomite. Thus, in their

chemistry, most brucite marbles either correspond to dolomite or occupy a position intermediate between dolomite and calcite, while mineralogically they all are intermediate between pentacite and purely calcitic and purely dolomitic rocks.

Thus the isolated position of brucite marble in classifications is not justified petrographically. All common marbles, not more magnesian than dolomite, can be represented as consisting of three main components — calcite, dolomite, and pentacite. Inasmuch as ideal examples corresponding to these terms are rare, and rocks are represented instead by the entire range of intermediate composition, it is expedient to differentiate certain ranges for individual rocks. A ternary diagram (Fig. 1) illustrates the ranges of the proposed varieties.

Essentially carbonate marbles are subdivided into three groups: calcitic, dolomitic-calcitic, and dolomitic, similar to the groups recognized in the classification of carbonates. This differentiation, however simple, reflects the criterion of composition.

It is expedient to keep the general name brucite marble for all marbles carrying brucite. However, such historic names as pentacite and predazzite should be preserved for brucite-calcitic rocks, supplementing them by dolomitic predazzite and dolomitic pentacite for those rocks which carry considerable dolomite along with calcite.

The wisdom of the proposed differentiation is demonstrated by the distribution in the triangle (Fig. 1), of points obtained from an analysis of the Aldan contact marbles, recomputed for the end members assumed, with the exception of the insoluble residue. We see that all brucite marbles with the general CaO:MgO ratio (with magnesium in metamorphic silicates taken into account) not exceeding that in dolomite, have fallen into the areas of pentacite and dolomitic pentacites.

Although the limited distribution of insoluble minerals in marbles makes the mineral composition of the soluble fraction the dominant factor, it is expedient to introduce the most common silicate present, in the rock name, e.g., forsterite-bearing dolomitic-calcitic marble.

The varietal names of marble so designated do not imply any genetic features, other than suggesting that they are metamorphic rocks. In composition, they either may correspond to the original sedimentary rocks or else be the results of a migration of magnesium and calcium. Where it is known for certain that the chemical composition of a

rock has undergone a substantial change in the process of metamorphism, this is best expressed in the adjective, "secondary." Thus, in the Aldan marble contacts, which we have studied, dolomite gave rise to pen-
catite which — with its brucite leached out — gave rise to secondary predazzite and dolomite-calcitic and calcitic marbles [12].

of protobrucite pencaite and predazzite for the second case.

In protobrucite marbles, dolomite may be present both as a result of dedolomitization and as a result of its incomplete replacement by aggregates of brucite and calcite [13]; in apopericlast brucite marble, on the other

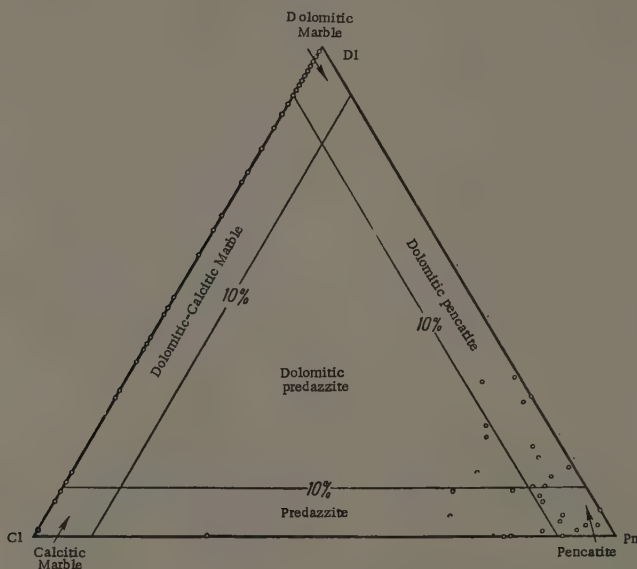


FIGURE 1. Classification of carbonate and brucite marbles not more magnesian than dolomite.

Circles mark the composition of analyzed Aldanian marbles; Cl -- calcite; DI -- dolomite; Pn -- Pencatite.

In most brucite marbles, brucite originates as a pseudomorph on periclase, where it forms isometric fibrous aggregates with relicts of periclase. Rarely, however, the dolomite is directly replaced by an aggregate of tabular brucite and calcite [14]. Whenever it is possible to establish the mode of origin of brucite marble, it should be reflected in the rock name. This is much simpler in the first of the above-named examples, because the fibrous brucite pseudomorphs on periclase are extremely conspicuous; the tabular brucite, on the other hand, can be formed in a recrystallization of pseudomorphic fibers of brucite aggregates. Accordingly, apopericlast brucite and protobrucite marble may be differentiated. Inasmuch as apopericlast marbles are by far the most common, the terms pencaite and predazzite are best retained for marbles formed as a result of a complete dedolomitization, using the names

hand, where the dolomite dissociation takes place throughout the body of a rock, dolomite usually forms in redolomitization. Because of that, it is more correct to refer to dolomite-bearing protobrucite marbles as "dolomitic," without any reference to the manner of its origin; by the same token, apopericlast marble may almost always be referred to as "dolomitized." This name, however, should be applied only when the redolomitization process has been proved.

Besides the common rocks belonging to the triangle calcite-dolomite-pencatite, there are among marbles not more magnesian than dolomite some rare inadequately known varieties which should be included in the classification for completeness. Here belong, first of all, the peculiar borate marbles, with coitoite marble from the Suian area, Korea [32], the most typical among them. This rock is

similar to pentacite, except for cotoite ($3\text{MgO} \cdot \text{B}_2\text{O}_3$) instead of brucite. The theoretical mineral content in pure cotoite marble is: cotoite, 38.8%; calcite, 61.2%, by weight. A number of other typical varieties should be available after a detailed study of borate marbles.

2) Calciphyres

The main feature of silicate-carbonate rocks are determined chiefly by metamorphic silicates, with the carbonate fraction being subordinate. According to the nature of silicates, this group can be subdivided as follows: calcareous silicate calciphyre, whose

content or the initial addition of clay, in some common calciphyres formed from dolomite. These graphs are idealized, being constructed on the assumption that no material was added and only carbon dioxide and water were taken out in the metamorphic reactions. Mineral ratios, close to the ideal, are far from being common in calciphyres. For example, in the contact haloes about syenite intrusions in the Aldan, where brucite marbles are developed, brucite is commonly missing in the calciphyre intercalations, where the soluble fraction is represented by calcite alone, although some brucite should have been present there, judging from the amount of insoluble metamorphic minerals. On the

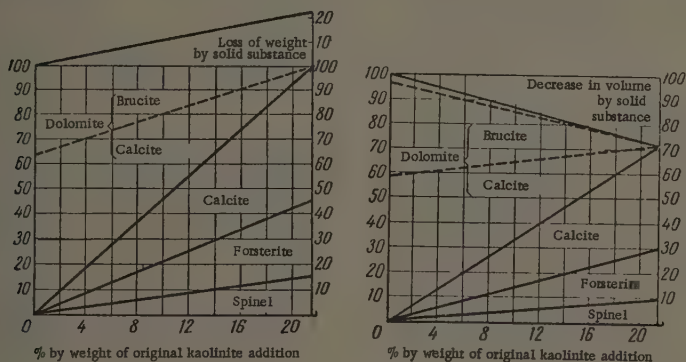
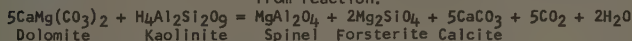


FIGURE 2. Relationship between the quantitative mineralogical composition of normal metamorphic spinel-forsterite calciphyres and the content of clay material added to the original dolomite (by weight %, to the left; by volume %, to the right). The determination was done from reaction:



carbonate fraction consists usually of calcite alone, and which contain typical calcareous silicates, such as wollastonite, epidote, calcareous-ferruginous garnets, feldspars, and some other minerals; and magnesian silicate calciphyre, containing variable amounts of carbonates (occasionally brucite), along with such typical insoluble magnesian minerals as talc, tremolite, forsterite, and spinel. It appears that calcareous-silicate calciphyres originate almost always from calcareous rocks, while the magnesian silicate ones originate from magnesian carbonate rocks.

Composition of the soluble fraction is most variable in calciphyres which have formed in dolomites and dolomitic limestones contaminated by terrigenous material. Figures 2-5 present the relationship between the quantitative ratios of minerals and the silica

other hand, consistent calciphyre beds commonly carry up to 60 to 70% forsterite, while the maximum amount possible in normal metamorphism is only 40%, by weight. The origin of such calciphyres, which have been formed in the Aldan contacts at the expense of dolomitic layers enriched in terrigenous material, can be explained only by an intensive metamorphic differentiation, with magnesia and lime migrating over considerable distances. Such metamorphic differentiation also can lead to the formation of purely silicate magnesian hornfels layers in metamorphic dolomite [30].

Thus most meta-carbonate rocks with the addition of silicate minerals are best represented by a triangle, consisting of three components: calcite-dolomite-hornfels (Fig. 6), where hornfels is a collective name for the

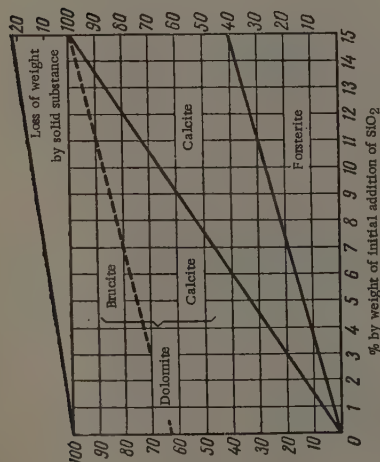
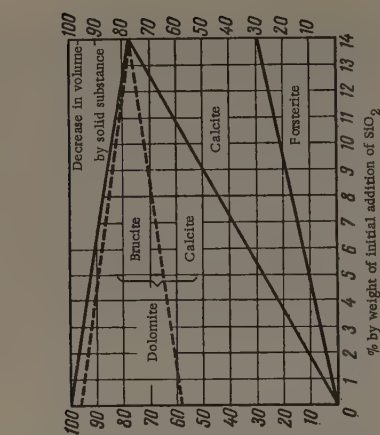


FIGURE 3. Relationship between the quantitative mineralogical composition of normal metamorphic forsterite-bearing marbles and forsterite calciphyres, and the addition of quartz in the original dolomite weight by %, to the left; by volume %, to the right). The computed reaction is as follows:

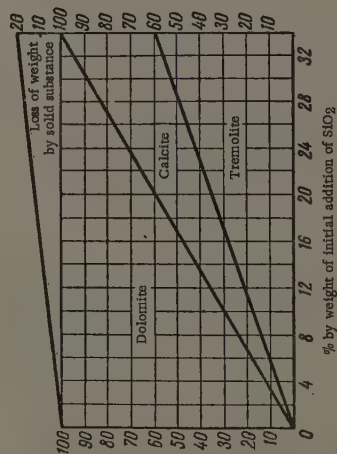
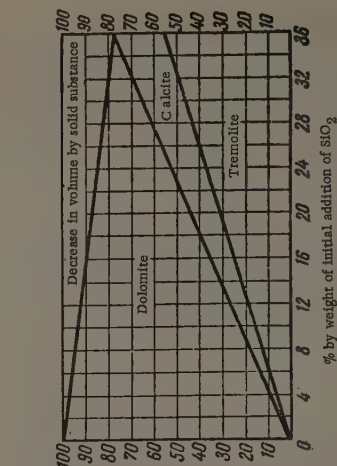
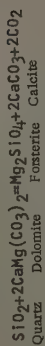
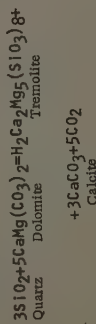


FIGURE 4. Relationship between the quantitative mineralogical composition of normal metamorphic tremolite-bearing marbles and tremolite calciphyres, and the additions of quartz in the original dolomites (weight by %, to the left; by volume %, to the right). The computed reaction is as follows:



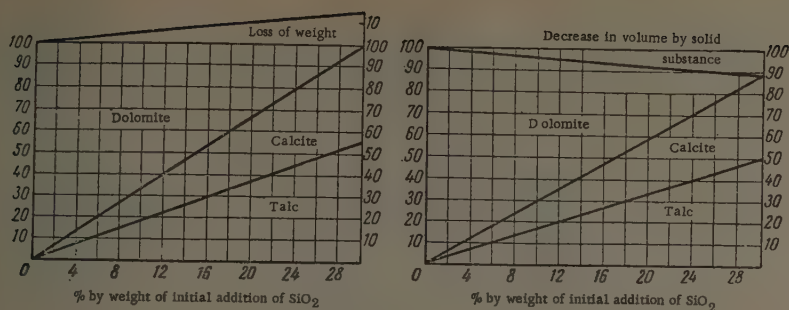
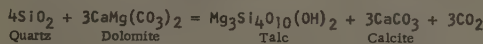


FIGURE 5. Relationship between the quantitative mineralogical composition of normal metamorphic talc-bearing marbles and talc calciphyres, and the additions of quartz in the original dolomites (by weight %, to the left; by volume % to the right). The computed reaction is as follows:



insoluble fraction of metamorphic minerals. In such a triangle, all calcareous-silicate calciphyres are located practically in the area where the carbonate fraction is essentially calcite, while the magnesian-silicate calciphyres will fall into a much wider compositional range.

Shown along the lines connecting the dolomite point of this composition triangle with the corresponding points on the calcite-hornfels side is the relationship between the composition of dolomitic calciphyres formed from contaminated dolomites, in pure metamorphism (Figs. 2-5), on one hand, and the original terrigenous fraction, on the other. However, more diversified compositions are possible in the presence of an extensive migration of matter — up to the formation of hornfels and skarn. Compositions which tend toward the dolomite-hornfels side cannot originate in normal metamorphism because dedolomitization with the formation of calcite takes place in that event in contaminated dolomite. However, rocks of this composition are formed during metamorphic differentiation, with the addition of magnesium. We have observed them in contact-metamorphic dolomites of the Aldan and Malyy Khingan where the entire cementing body of a calciphyre, in large segments, is represented by dolomite, with 40 to 50% forsterite. Rocks of a similar type are known from magnesian carbonate sequences of the Baykal region. It is therefore expedient to differentiate dolomitic calciphyres, whose carbonate fraction is mostly dolomite with less than 10% calcite.

Calciphyres are named according to one or more insoluble minerals best developed in them, the less common mineral first, e. g.,

spinel-forsterite dolomitic calciphyre. This name immediately conveys the idea that the spinel and forsterite content is over 10%, with the spinel predominant, and that the main body is over 10% dolomite.

As long as there are calciphyres with some brucite in a considerable body of silicates, it becomes necessary to differentiate brucite-bearing calciphyres and to regard meta-carbonates as consisting of four end members — calcite, dolomite, pencatite, and hornfels. Figure 7 presents a tetrahedron with these four components for its apices. A reservation should be made right away, that this tetrahedron represents only those rocks whose soluble fraction is not more magnesian than dolomite, while varieties richer in magnesium are possible as a result of the magnesium concentration in insoluble metamorphic minerals. Besides the two familiar triangles, the tetrahedron has two more faces. Compositions tending toward the pencatite-hornfels side of triangle calcite-pencatite-hornfels are rather improbable because it is difficult to imagine conditions under which calcite which originates in the formation of insoluble minerals will be replaced by brucite, in the amount just right for pencatite. Accordingly, rocks of such a composition are not differentiated.

The interior of the tetrahedron is taken over by calciphyre with brucite, where the dolomite content is over 10% (brucite-carrying dolomitic calciphyre). Such rocks have been observed in the Aldan. In the Aldan, where redolomitization takes place with an addition of magnesium, dolomitization of calcite in brucitic-calcitic rocks is more intensive than the recarbonitization of

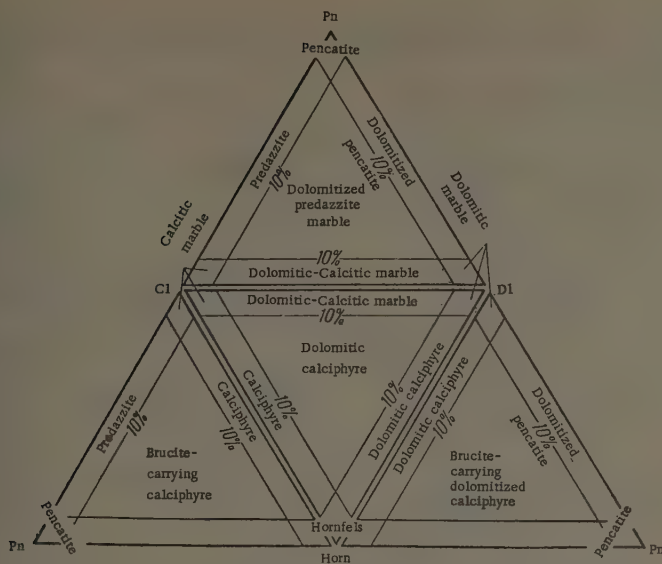


FIGURE 7. Classification of most common meta-carbonate rocks, not more magnesian than dolomite.

Symbols the same as in Figs. 1 and 6.

material in carbonate rocks has been ascertained positively, such rocks may be referred to as normally metamorphic calciphyre. Rocks formed with an addition of silicate material, and accompanying the skarn in a metasomatic zone, or replacing them in segments of inadequate metasomatism, may be called near-skarn calciphyre, in analogy with D. S. Korzhinskiy's term for metasomatically slightly altered, endocontact aluminosilicate rocks.

3) Hornfels and Skarn

It is difficult to select a collective name for a complex group of essentially silicate meta-carbonate rocks — crystalline schist, hornfels, and skarn. Without getting into the details of this problem, we stress the fact that their suggested differentiation into calcareous and magnesian varieties [6, 30], according to typical metamorphic silicate components, can be supplemented by a definite quantitative boundary, wherein rocks with the CaO:MgO ratio greater than 1:1 are assigned to calcareous varietal types, while those with a ratio less than 1:1 are assigned to magnesian types. The most typical genetic varieties in this group are hornfels, among metamorphic rocks; and skarn among the metasomatic.

2. Metamorphosed Carbonate Rocks More Magnesian Than Dolomites in Their Soluble Fraction

All of the foregoing rocks were not more magnesian than dolomite in their soluble fraction. Such compositions are most common in metamorphic carbonate rocks. However, there are more magnesian varieties whose main components are commonly of a sedimentary origin; others are formed as a result of metamorphic differentiation. Such rocks are most conveniently considered in a calcite-brucite-magnesite-dolomite quadrangle (Fig. 8). In this diagram, the earlier triangle of marbles will occupy a portion of the calcite-brucite-dolomite triangle. The familiar rocks of that triangle — and richer in brucite than pencatite — primarily represent metasomatic veins of brucite in brucite marbles, which occur in the Aldan to a very small extent but are very thick in Canadian deposits, in California, and especially in Nevada, U.S. [18].

However, the enrichment in magnesia at the expense of metasomatic brucite leads sometimes not to the formation of sub-monomineral brucite veins but rather to calcite-brucite rocks with a dispersion of tabular brucite, in an amount considerably larger than in pencatite, as witness the Gornaya Shoriya brucite

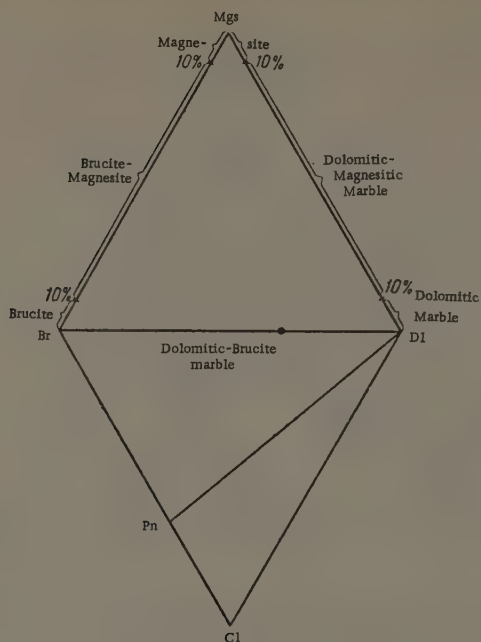


FIGURE 8. Classification of marbles more magnesian than dolomite.

Br -- brucite; D1 -- dolomite; Mgs -- magnesite;
Pn -- pentacite.

marbles. On the other hand, there are Rutherglen (Ontario) brucite marbles [25] where — with the dispersed brucite content not exceeding that in pentacite — the carbonate is represented in places almost wholly by dolomite. Such brucite marbles, somewhat richer in magnesium because of the more rapid dolomitization of calcite compared with the recarbonatization of brucite, also occur in the Aldan. In an ideal case of dolomitization of calcite alone, such rock will consist of brucite and dolomite, with a molecular ratio of approximately 2:1, or with the following theoretical mineral content: brucite, 35.1%; dolomite, 64.9%, by weight.

Brucite marbles enriched in magnesium are not well known. It is expedient, therefore, to differentiate them in a general way, for the time being, calling them, to distinguish them from pentacite, calcite-brucite and dolomite-brucite marbles, and leaving open the question of their further differentiation.

As far as we know, magnesite does not

occur in direct association with calcite, in metamorphic rocks; magnesite veins in calcitic marbles, for example, are always hemmed with a contact-reaction fringe of dolomite [24]. On the other hand, there are known magnesitic dolomitic marbles and monomineral magnesites. Accordingly, a trinomial division of the dolomite-magnesite rock series can be set up, quite similar to the calcite-dolomite series. In addition, magnesite has been observed in pseudomorphs on vein brucite [19]; consequently, still another transitional variety, brucite-magnesite, is possible. Minerals of the compositions represented in the interior of the brucite-magnesite-dolomite triangle are unknown to us.

The proposed classification of meta-carbonate rocks can be presented as shown below. Inasmuch as meta-carbonates more magnesian than dolomite in their soluble fraction, have been inadequately studied for the effect on them of silicate additions, the best course appears to be to include them in the marble group.

CLASSIFICATION OF METAMORPHIC CARBONATE ROCKS

1) Marbles (with less than 10% metamorphic silicates)

The typical metamorphic silicate is introduced into the name; e. g., forsterite-bearing calcitic marble.

A. Essentially Carbonate Marbles (with less than 10 3/4% pentacite component, i. e., less than 4% brucite)

Marbles not more magnesian than dolomite:

Calcitic (less than 10% dolomite);

Dolomite-calcitic (10 to 90% dolomite);

Dolomitic (less than 10% calcite);

Dolomitic (less than 10% magnesite).

Marbles more magnesian than dolomite:

Dolomitic-magnesitic (10 to 90% magnesite);

Magnesitic (less than 10% dolomite).

Genetic varieties of marble:

1) those having undergone recrystallization with a small change in carbon dioxide content;

2) with definitely established considerable metasomatic alterations of principal components — magnesia and lime. Such marbles should be referred to as "secondary."

B. Brucite Marbles and Essentially Brucite Rocks

Marbles not more magnesian than dolomite:

Pentacite (less than 10% dolomite; less than 10% calcite, not equivalent to brucite; 25.0 to 36.8% brucite);

Predazzite (less than 10% dolomite; 10 to 90% calcite, not equivalent to brucite; 4 to 33% brucite);

Dolomitic pentacite (10 to 90% dolomite; less than 10% calcite, not equivalent to brucite; 4 to 33% brucite);

Dolomitic predazzite (10 to 80% dolomite; 10 to 80% calcite, not equivalent to brucite; 4 to 33% brucite).

Brucite marbles and essentially brucite rocks, more magnesian than dolomite:

Brucite marbles and essentially brucite rocks, more magnesian than dolomite:

Calcite-brucite marble (brucite content higher than in pentacite; calcite content lower);

Dolomite-brucite marble (brucite content higher than in dolomitic pentacite with the same dolomite content; only brucite and dolomite present in extreme varieties);

Brucite (no less than 90% brucite);

Brucite-magnesite (10 to 90% brucite).

Genetic varieties of brucite marble:

1) apopericlastic (with relicts of periclase or pseudomorphs of fibrous brucite on it);

2) protobrucitic (free of periclase relicts and the pseudomorphs of fibrous brucite on periclase, but with primary tabular brucite).

In the presence of authentic primary fibrous brucite, the corresponding varieties should be called protobrucitic: protobrucitic pentacite, dolomitic protobrucitic pentacite, dolomitic protobrucitic predazzite or dolomitic-protobrucitic marble, leaving the simple names, given above, to the more common apopericlastic marbles.

C. Borate Marbles (with soluble borates)

Cotoitic marble (theoretical composition: cotoite, 33.8%; calcite, 61.2%, by weight)

2) Calciphyres (metamorphic silicate content, 10 to 90%)

Depending on the insoluble component (metamorphic silicates), they are divided into calcareous-silicate and magnesian silicate.

A name is given after one or more insoluble minerals commonly present in a rock, the less common first, e. g., spinel-forsterite calciphyre. Depending on their soluble (carbonate) fraction, they are classified as follows:

Calciphyre (10 to 90% calcite; less than 10% dolomite; less than 10% pentacite, i. e., 4% brucite);

Dolomitic calciphyre (10 to 90% dolomite; less than 10% pentacite);

Dolomitic calciphyre (less than 10% calcite; less than 10% pentacite; 10 to 90%

dolomite);

Brucite-bearing calciphyre (10 to 80% pentacite, i.e., 4 to 29% brucite; less than 10% dolomite);

Brucite-bearing dolomitic calciphyre (10 to 80% pentacite; no less than 10% dolomite).

Genetic varieties of calciphyre are as follows:

1) normal-metamorphic, where metamorphic silicates have formed from the terrigenous addition;

2) near-skarn calciphyre, formed from the addition of magmatic silica and alumina to carbonate rocks.

3) Hornfels and Skarn (carbonate content less than 10%)

Magnesian (with the CaO:MgO molecular ratio not over 1:1);

Calcareous (with the CaO:MgO molecular ratio higher than 1:1).

It can be noted, in conclusion, that it does not make much difference, in standard petrographic work, whether a rock percentage is determined by weight or by volume; the difference is so insignificant as to fall, generally, within the limit of error of qualitative mineralogic computations.

III. THE FUTURE TREND IN CLASSIFICATION

The proposed classification undoubtedly can be refined and improved. There are several possible areas of such broadening and development: 1) a systematization of rocks not now included in the classification; 2) a more detailed differentiation of the already classified rocks; 3) a further differentiation of genetic subdivisions; and 4) introduction of a structure criterion.

A development of the classification in the first area is possible by including siderites which occur in paragenetic association with magnesites in meta-carbonates. It should be noted that the classification does not include silicate-magnesite rocks, such as talc-magnesite bodies in metamorphic magnesian-carbonate rocks [15]. By the same token, it is possible to include in this classification, graphitic carbonate rocks, etc.

The possibility of a more detailed differentiation within the groups and varieties pertains first of all to the inadequately studied

brucite marbles with a higher magnesium content. More definite differentiations according to the typical and common paragenesis of silicates should be introduced for calciphyres and essentially silicate rocks; specifically, the V.M. Goldschmidt classification of hornfels types can be reviewed from a modern point of view. Such a task is already underway, being reflected in publications of D.S. Korzhinskiy, N.L. Bower, and F.D. Turner; what is needed is a careful compilation and systematization of material on hand.

The genetic aspect of the classification can be strengthened, with some precautions. Some of the possible areas of development are the introduction of a more definite temperature criterion for the metasomatic types, of the reaction conditions for metasomatic agents, etc.

The introduction of a structural criterion in a rock classification does not appear to be advisable at the present time. The rock names already introduced based on this criterion seem to be superfluous. Thus, the historical distinction between massive hornfels (chiefly contact metamorphic rocks) and crystalline schist (regionally metamorphosed rocks) often becomes too formalistic, as has been noted in the literature [16]. Contact metamorphic rocks are sometimes schistose, while regionally metamorphosed rocks are locally massive. This circumstance has led to such neutral terms as diopside rock which is often assigned to the traditional regional-metamorphic group of crystalline schists, although it usually is a massive rock, essentially corresponding to magnesian skarn (a typical contact-metamorphic rock) but developed on a regional scale. Accordingly, it would be expedient to replace the terms reflecting the structure criterion by a collective name for all essentially silicate rocks which are the metamorphic analogues of carbonate rocks (magnesian-calcareous meta-silicates?). There also is need for collective names of normal-metamorphic and metasomatic rocks and for their regional and contact varieties; this is because the similarity in the regular patterns of formation becomes more and more apparent. The structure criterion undoubtedly should be subordinate in a nomenclature; in that respect, the structure of the name "schistose marbles" [1] appears to be effective. A subordinate role in a nomenclature may be given to such structural criteria as grain size and relationships.

Thus the proposed classification can be refined, in the future, by introducing supplementary petrographic varietal terms, by their qualitative mineralogic criteria (paragenesis), and by the criteria of their structure and origin. Nevertheless, we believe that our

classification, because of its simplicity and the broad range of meta-carbonate rocks it embraces, may become a basis for a single system. We also believe that, with all possible modifications and supplements, the objective criterion of composition (qualitative and quantitative relations of minerals) should be kept as the fundamental one, with the often-controversial origin of a rock used as a secondary criteria of classification. Another reason for the paramount importance of composition in classification is that it constitutes a premise for the search for minerals.

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POSSIBLE WAYS IN WHICH ALKALINE MAGMAS MAY HAVE BEEN FORMED IN GEOSYNCLINAL REGIONS (TURKESTAN-ALAY AS AN EXAMPLE)^{1,2}

by

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It is common knowledge that alkaline rocks occur primarily in transition regions between a folded zone and a platform and are not typical features of folded mountain regions. There are exceptions, however; intrusions of alkalic composition are found also in the active parts of folded zones and in the domes of central uplifts. These intrusions, however, were formed during an orogenic era in which intensive dome-formation occurred as the final stage in the development of a geosyncline. Some of the clearest examples of such intrusions are the alkaline massifs in the Turkestan-Alay mountain system.

The most characteristic features of the alkaline rocks in this region are as follows:

1. Alkaline rock massifs occur exclusively in the watershed part of the Turkestan-Alay mountain system and can be traced in the form of individual outcrops over a distance of some 300 kilometers.

2. Practically all the intrusive formations in the Turkestan-Alay system (with the exception of individual dikes consisting of ultrabasic rocks) belong to the late, concluding stages of the Paleozoic folding. The era of greatest magmatic effects coincides with the Upper Variscan phase of folding and occurred at the end of the Paleozoic.

3. We can now regard it as definite that the intrusive rocks formed at the end of the upper Paleozoic belong to the following sequence, from older to younger: a) equigranular granodiorite and quartz diorite; b) porphyritic and equigranular granite; c) rocks of the alkaline group; d) leucocratic fine-grained, and not infrequently tourmaliniferous granite.

There was accordingly a deviation, in the direction of alkaline magma formation, at a certain stage in the normal process of differentiation from more basic to more acid magma. This deviation seems to have been due to special physical and chemical conditions.

4. Intrusions of the alkaline group usually coincide with dome-shaped anticlinal folds or with major regional fractures. The alkaline massifs are generally small (8 to 10 square kilometers) but some occupy as much as 60 square kilometers.

5. The enclosing rocks are predominantly limestone, sandstone and shale belonging to the Paleozoic strata. It must be noted that limestone is common throughout the stratigraphic cross section of the Turkestan-Alay system, including the oldest formations.

6. A close spatial connection is observed between the alkaline group and the granitoid rocks.

7. The alkaline rocks are represented by the entire range of varieties, from nepheline syenite to alkaline granite.

8. Three groups of alkaline massifs are found: a) rocks entirely compounded of nepheline syenite; b) rocks composed entirely of nepheline syenite, in which there is alkaline syenite, syenite, quartz syenite and in places alkaline granite along with the nepheline syenite; c) massifs in which nepheline or alkaline syenite plays a distinctly subordinate part.

9. The question of relative ages within a group of alkaline rocks is still a matter of controversy; gradual transitions between nepheline, alkaline and alkaline earth syenites are always being recognized. Sometimes, granitoid rocks are found within the massifs.

These sometimes shade off gradually into alkaline varieties; in places the two types intersect; in some cases the alkaline rocks,

¹Vozможnyye puti formirovaniya shchelochnykh magm v geosinklinal'nykh oblastyakh.

²Printed in the form of a discussion [Russian Editor's note].

in other cases the granitoids, prove to be the older.

In cases where the transition is gradual the granites are highly alkaline. In the case of intersection contacts we think the alkaline and granitoid rocks should correctly be attributed to the more recent phases of a single intrusive cycle, and the granite to the latest stage of intrusion of leucocratic biotitic granite.

On this question we agree with Butakova [1], who attributes the granitoid and alkaline rocks of the Isfayram massif to different stages of magmatic activity.

10. The alkaline rocks, particularly the nepheline syenite, are not uniform in composition, either from one massif to another or within the same massif. The composition of the nepheline syenite is to a considerable degree determined by the quantity and composition of the assimilated rocks, the intensity of the postmagmatic processes and the contact effect of the leucocratic granite. In a good many instances, however, the only explanation for the heterogeneity of composition in the alkaline massifs — especially when syenite, alkaline syenite and nepheline syenite enter into their structure — is that the magma has a different composition in different parts of the intrusion. This would also seem to account for the varied composition of the Shakhi-Safet massif [11], the presence of alkaline syenite sectors in the Khodzha-Achkan nepheline syenite massif, of nepheline syenite in the alkaline syenite of the Kul'psk massif and so forth.

11. Study of the relationships between the alkaline massifs and the enclosing rocks provides grounds for the contention that these massifs were formed as a result of intrusion. The process of magmatic intrusion was accompanied by considerable mechanical strains; this is borne out by the variation in the strike and dip and fractionation of the laminated enclosing rocks.

The explanation we have suggested for the conditions under which alkaline magmas were formed is based on postulates made by Korzhinskiy in a number of his works [6-10].

1. First of all, we admit that solutions which pass through magma do in fact exist. These solutions consist of a stream of water particles, along with certain precipitates or components, and are of deep-seated origin. The problem of solutions which pass through magma has been examined in detail by Korzhinskiy [7, 8], and we merely note that the reality and necessity of such solutions cannot be confirmed in the case of comparatively small massifs which have lost their direct

connection with the magmatic source region. Early metamorphism and magmatic substitution in connection with such massifs is usually very poorly developed. On the other hand, in the case of batholithic bodies with which processes of intensive granitization of the enclosing rocks are connected and which have roots that go down to very great depths, we can readily assume the existence of solutions that pass through magma.

The granitization processes which occur in large areas and are very pronounced within the old crystalline shields seem to be situated in direct connection with the solutions which have passed through magma. Such regions are characterized by widespread development of gneiss and migmatite. Kopteva-Dvornikov's statements [5] that direct observations of intrusive massifs do not confirm that such solutions really exist refer solely to massifs in which the granitization processes are poorly developed.

2. Granitization in the broad sense of the term is impossible unless there has been a transition from primary sedimentary and metamorphic rocks to the molten state.

3. When a strong-base weak-acid salt is dissolved the acidity of the solution falls. The coefficient of activity of the bases, especially of the strongest bases, such as potassium and sodium, rises.

This rule, which is well known from electrochemistry, has been theoretically substantiated by Korzhinskiy [9].

On the basis of the theoretical postulates and the characteristic features of the Turkistan-Alay intrusions listed above, we shall now attempt to describe the process of alkaline magma formation. After the intrusion of a first (equigranular granodiorite - quartz diorite) and a second (porphyritic granite) phase of the post-lower Permian intrusion complex, the composition of the magma in the magmatic source region was of course substantially granitic. Owing to the action of solutions passing through the magma into the rocks, and the magmatic substitution of these solutions at certain stages in the tectonic-magmatic development of a geosynclinal region, the size of the source area may increase or, conversely, may diminish through crystallization of the peripheral parts, as a result of the damping of these processes.

Let us assume that over a significant extent of the contact the magmatic basin has come into contact with limestone or dolomite. The calcium and magnesium concentration in the solution will then increase sharply at the front of the magmatic substitution. This in turn leads to an increase in the coefficient of

activity of the bases in general, and a consequent increase in the chemical potentials of the alkalis in solution. The result is that the potassium and sodium begins to be converted, through diffusion, from a solution passing through the magma, into a magma, while silica begins to change from a magma into a solution, and a magma of enhanced alkalinity is formed. Since the diffusion of components from one part of the system to another is determined by the difference in chemical potentials, this diffusion will cause the potassium and sodium to move in a contrary direction to the solutions. Those parts of the granitoid magma near the front of magmatic substitution will then also show enhanced alkalinity, and so an aureole of reflected alkalinity is formed.

It is important to emphasize that the front of magmatic substitution should be regarded as a zone of fairly considerable width with very uneven creek-like contacts of magmatic molten matter with the enclosing rocks. This zone is saturated with lumps of the enclosing rocks which have undergone magmatic substitution. That such a process really does occur is confirmed by the frequent presence of an aureole of enhanced acidity in the granite at its point of contact with the dolomite, limestone or intrusions of basic composition. The stream of components of the solutions passing through the magma will be to some extent maintained in the magma through diffusion from the deeper levels of the source region to the roof of the magmatic basin. If the solutions passing through the magma have the character of infiltrations (as is most likely), the arrival of new portions of the solution, of normal alkalinity, in the zone of reflected alkalinity, creates conditions under which potassium and sodium are diffused in the reverse direction, from the magma into the solution. This will lead to an inverse change in the alkalinity of the magma, which will fall to normal. In this way, magmatic substitution of carbonatic rocks, accompanied by a movement of highly alkaline magma, produces a movement of the zone of normal alkalinity.

The thickness of the highly alkaline magma shell will be determined by many factors, in particular by the composition of the rocks which are in contact with the source region, the intensity and rapidity of the magmatic substitution, and the rate at which the solutions passing through the magma are moving. It can be completely absent in places where silicate rocks are undergoing substitution. Consequently, the alkalinity of the magmas entering into the upper structural stages in the form of intrusions may vary. When the magmatic shell is very thick at a place where intrusions branch off, the intruding magma is composed entirely of nepheline syenite; when the thickness at such places is small, the

intruding magma is composed of alkaline granite. The alkalinity of the intruding magmatic mass may not be the same in different parts of this mass. If the processes of intrusion and crystallization of the intrusions are sufficiently rapid, the mass may fail to acquire an even composition by way of diffusion, with the result that massifs of non-homogeneous structure are formed, with gradual transitions between rocks of various degrees of alkalinity. The penetration of intrusions of leucocratic fine-grained granite occurred in a period of reduced tectonic and magmatic activity from deeper parts of a magmatic basin, by which time the peripheral parts of this basin might already have crystallized out.

The small size of the nepheline syenite massifs can be readily accounted for in terms of the pattern of development which we have suggested. In cases where large volumes of intrusive mass emerged from the source region, the alkaline magma of the outer shell would in fact be dissolved in the considerably greater volume of granitic magma.

The following conditions are accordingly necessary for the formation of alkaline magma: 1) the presence of limestone or dolomite in contact with a magmatic source region, 2) granitic composition of the magmatic molten matter in the source region, 3) intensive magmatic substitution of the solid rocks enclosing the source region, 4) tectonic conditions which favor the introduction of small inclusions from the peripheral parts of the magmatic source region.

The question that now arises is why cases of alkaline rock formation are comparatively rare at the contacts between granitic intrusions and limestone. The formation of granodiorite, quartz diorite and diorite of normal alkalinity is considerably more frequent. Zharikov [3] associates this phenomenon with different ratios between the rates of diffusion and infiltration. If the infiltration rate of the solution is higher than the rate at which the alkalis are counter-diffused, endocontact zones of high alkalinity cannot form.

In our view, however, this phenomenon would be more correctly accounted for by the absence of any intensive influx of solutions through the magma. This can occur when there is a small volume of intrusive magmatic mass and the direct link between the intrusion and the magmatic source region is lost.

The process of magmatic substitution is in this case effected by diffusion, and the peripheral part of the intrusion is enriched with components of the enclosing rocks, in particular by calcium in contact with limestone. Zharikov [3] has suggested calling this

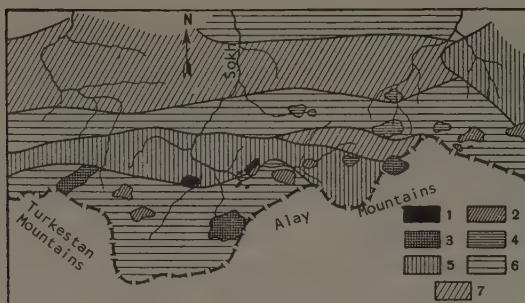


FIGURE 1. Distribution of intrusive rocks on the northern slopes of the eastern part of the Turkestan Mountains and the western part of the Alay Mountains.

1 -- Fine-grained leucocratic granite; 2 -- rocks of the alkali group; 3 -- porphyritic granite; 4 -- gradodiorite and quartziferous diorite; 5 -- upper Paleozoic deposits predominant (from middle Carboniferous to Permian); 6 -- middle Paleozoic (upper part) predominant (from Middle Devonian to lower Carboniferous); 7 -- middle Paleozoic (lower part) predominant (from Lower Silurian to Lower Devonian).

process, which is usually called assimilation, "magmatic substitution by diffusion" to distinguish it from magmatic substitution by infiltration.

Under conditions of relatively rapid crystallization when the connection between the intrusion and the magmatic source region has been lost, the behavior of the alkalis cannot be regarded as fully mobile; this means that there is no constant influx through the magma of solutions carrying different components, particularly alkalis.

In this case too, if the chemical potential of the alkalis in solution rises, they will be diffused into the magmatic molten matter. Their content in the solution, however, is negligible in comparison with their content in the magma, and therefore there can be no significant change in the magma composition when the quantity of solution is very small. Consequently the alkali content in the crystallizing rocks is not determined by their chemical potentials in the solution, but depends on the quantity of alkalis in the magma of the rocks assimilated by the magma. On the other hand, in endocontacts of granitic massifs with limestone, and especially with dolomite in which there has been intensively developed metamorphosis of the magmatic stage, rocks of high alkalinity must necessarily occur.

The pattern of events which we have suggested to account for the formation of alkaline

magmas is essentially no more than a development of Korzhinskiy's ideas [8]. It equally explains the formation of endocontacts in granitic massifs of high alkalinity.

It will be seen that our suggested pattern of events to a large extent overlaps the Daly-Shand hypothesis [2-13]. In both cases the interaction of granitic magma with limestone is essential. Our point of view, however, is based on the theoretical postulate that the interaction of a solution with strong-base and weak-acid salts raises the alkaline activity in the solution.

The question of solutions passing through magma is more controversial. If, however, one allows for the fact that the majority of investigators [4, 12, 13, 14], attribute the decisive role in alkaline magma formation to floods, which can occur side by side with the passage of solutions through the magma, it is clear that we are not introducing any additional element of assumption into the process of alkaline rock origins. The widely held opinion of Shand, on the other hand, proves on examination to call for a considerably greater number of theoretically and experimentally unsupported assumptions. The reaction of the molten matter with calcite, for example, is reduced to a reaction between albite and calcite, and the formation of carbonate-sodium silicate compounds is thereby ignored. These compounds, along with the solutions and volatile matter, must be transported into the upper parts of the magmatic

basin and then react with molecules of albite and anorthite to form nepheline. It is not clear why these compounds form in the lower parts of the magmatic source region and react in the upper parts, without passing on further, along with the solutions.

It will readily be seen that this outwardly presentable hypothesis is built on too many assumptions. It depends almost entirely on a single prerequisite: that there should be a connection between the nepheline syenite and the carbonatic rocks; but the actual mechanism of magma formation by this method would be complicated and not very likely to occur.

In conclusion, it must be emphasized that the hypothesis we have suggested refers solely to the formation of alkaline magmas in geosynclinal regions, but not to alkaline rocks formed under platform or semiplatform conditions.

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THE ROLE OF ALUMINUM IN THE FORMATION OF MINERALS IN CRYSTALLIZATION OF BASIC SILICATE MELTS¹

by

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Depending on crystallization conditions, many melts of the same chemical composition may form crystalline products differing not only in structure and morphology of individual minerals but in phase composition as well. Aluminum is especially important in the explanation of differences in such mineral formations for many basic and many ultrabasic silicate melts, because it participates in the structure of crystalline lattices of the principal minerals so originated.

Feldspars, pyroxenes, minerals of the Melilite group, and spinel minerals carry different but substantial amounts of aluminum. The role of aluminum is considerable in isomorphous replacements typical of complex silicates and spinel minerals. This diversity of possible manifestations of aluminum in the crystalline phase is what predetermines the changes in the facies composition of rocks formed from melts under different crystallization conditions.

The peculiar role of aluminum in the formation of minerals is expressed as follows:

1. The dual manifestation of aluminum in silicates: first, in aluminosilicates where Al^{+3} , like Si^{+4} , is surrounded by oxygen ions, in the crystalline lattice; and second, in silicates of aluminum where Al^{+3} , like Mg^{+2} , is surrounded by six oxygen ions. As will be shown below, the coordination number of aluminum in a crystalline lattice of silicates undoubtedly depends on the conditions of mineral formation.

2. The joint appearance of aluminum in spinel minerals and silicates, in the crystallization of ultrabasic melts. Under nonequilibrium conditions of a crystallization process, various shifts are possible in the quantitative ratios of these crystalline phases, depending on the crystallization conditions.

3. A wide development of aluminum in

standard molecules of types $R^{++}R_2^{+++}SiO_6$, $R_2^{++}R_2^{+++}SiO_7$, and $R^{++}R_2^{+++}O_4$, participating in the formation of isomorphous mixtures. The qualitative and quantitative characteristics of isomorphous mixtures so formed, and the different form of the aluminum manifestations in the emerging crystalline phases, are very often determined by the conditions of mineral formation, with the isomorphous aluminum replacements depending to a considerable extent on its coordination number.

This diversified manifestation of aluminum in silicates, dependent on the crystallization conditions, is promoted by the favorable ratio of the ionic radius of aluminum to the radius of the oxygen anion (0.43), approaching the geometric difference between coordinations 6 and 4 (0.41) in the calculation of the critical stability for coordination polyhedrons.

As pointed out by A.I. Tsvetkov [9], as a result of its borderline position, aluminum is capable of building up crystalline structures in sextuple and quadruple coordinations; this is because the geometric boundaries of a coordination, fixed by the ionic radii ratio, are not quite rigid but vary depending on the conditions of mineral formation. The same borderline position promotes a diversified course of mineral formation, due to the extensive participation of aluminum in isomorphous replacements. Aluminum in coordination six, where its ionic radius coincides with the lower limit of stability, is readily replaced by larger ions; on the other hand, according to V.S. Sobolev, the aluminum ion is sufficiently large for coordination number 4, and it may be replaced by ions of a smaller radius [5].

We shall now turn to two examples of the different forms of manifestation of aluminum in silicates. We shall not dwell on structural features; rather we shall direct the reader's attention to the change in the phase composition of rocks depending on their formation conditions.

¹ Rol' al'yuminiya v mineraloobrazovanii pri kristallizatsii osnovnykh silikatnykh rasplavov.

Example 1. Samples obtained as a result of experimental fusing in the search for new

light-colored stone cast for facing of buildings. The chemical composition of rock material was as follows:

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO
44.9	16.6	0.3	7.3	30.9

The silicate melt was obtained from a synthetic furnace charge, at a temperature of 1,400 to 1,450°C, poured into containers and cooled off under somewhat different conditions, as follows:

A. The melt in a container was rapidly transferred to a muffle furnace, to crystallize "from the top," for one hour, at 900 to 950°C. The stone so obtained had a fine- and even-grained structure, in its peripheral parts, consisting of diopside (40 to 45%), β -wollastonite (10 to 12%), anorthite (9 to 12%), and helenite (up to 20%).

B. The central, and better crystallized, parts of the same melt contained considerably less helenite and wollastonite, appreciably more anorthite (15 to 18%), and somewhat more diopside. The formation of a mineral of the rankinite^a type, as described by V.V. Lapin [3] from blast-furnace slag, has also been observed here.

C. Glass, formed out of the melt by tempering in air, crystallized "from the bottom" in the muffle furnace, for three hours at a temperature of 950 to 1,000°. The sample so obtained had a uniform

structure, being mostly diopside (70 to 75%), whose refractive index ($N = 1.68$ to 1.71) suggests a considerable isomorphic addition of $\text{CaAl}_2\text{SiO}_6$ (up to 35%). In addition to diopside, the sample contained wollastonite (up to 20%) and occasional anorthite, in small tablets only. Table 1 shows the variations in the mineral composition of melts obtained from a standard molecular calculation of their chemical composition.

Conspicuous in this example are differences in the process of mineral formation, expressed chiefly in the variable amount of aluminum in the quadruple and the corresponding sextuple coordinations. Also conspicuous is a shift in the crystallization fields for plagioclase and pyroxene, brought about by the manifestation of a variable portion of aluminum in pyroxene, as an isomorphic addition $\text{CaAl}_2\text{SiO}_6$ in diopside.

The maximum relative amount of aluminum in quadruple coordination is related, here, to the most stable equilibrium course of the crystallization process (the central part of melt, in the crystallization "from the top"), while the minimum has been observed in the least stable equilibrium crystallization process, "from the bottom," out of a strongly supercooled state. Associated with the more stable equilibrium crystallization process also is, as it appears from the table, the more intensive differentiation of rock-forming oxides in mineral formation.

Example 2. Remelting of the Omega diabase — a rock well known in our stone-casting industry — with subsequent recrystallization under different conditions. The following variations in mineral formation can be indicated in this example:

A. A rock formed under natural geologic conditions is more than half feldspar, chiefly

Table 1
Variations in Mineral Composition of Melts

Variants	Calculated normal mineral composition						Ratio of Al with coordinate number 6 to Al with coordinate number 4
	Diopside $\text{CaMgSi}_2\text{O}_6$	$\text{CaAl}_2\text{SiO}_6$ in isomorphic mixture with diopside	Wollastonite CaSiO_3	Anorthite $\text{CaAl}_2\text{Si}_2\text{O}_8$	Helenite $\text{Ca}_2\text{Al}_2\text{SiO}_7$	$\text{Ca}_3\text{Si}_2\text{O}_7$	
A	40,5	3,2	11,4	16,5	28,4	—	0,042
	40,5	17,2		23,5		18,8	0,32
B	41,4	36,0	22,6			—	1,0

NOTE: Comma represents decimal point.

labradorite No. 54-55, and low-alumina pyroxene — enstatite-augite [6].

B. The experimental stone specimen, obtained by A.I. Tsvetkov [7], was made up of a more basic plagioclase (bytownite No. 75-80) and pyroxene of the diopside-hedenbergite series.

In this experiment, glass was obtained by tempering of a diabase melt; the glass was then annealed for a considerable period of time (2 to 12 days) at temperatures of 1,250 to 800°C, to establish crystallization conditions as completely in equilibrium as possible.

C. Cast stone samples, obtained from the same diabase under factory conditions, which I studied petrographically. These samples have a uniform, often typically "polygonal" structure and are made up chiefly of monoclinic pyroxene. The stone shows a monomineral tendency, with plagioclase (bytownite-anorthite) present mostly in variable and usually in comparatively small amounts (10 to 15%). The associated pyroxene has a complex composition, with the principal hedenbergite-diopside component including considerable isomorphous additions of type $\text{CaAl}_2\text{SiO}_6$, $\text{CaFe}_2^{+++}\text{SiO}_6$, and evidently $\text{NaAlSi}_2\text{O}_6$. These samples were obtained from a diabase melt, poured into containers (with a considerable drop in temperature), and then crystallized in annealing furnaces, at 900 to 950°C, with a subsequent slow cooling.

Inasmuch as in all those examples of the mineral phase combinations, the residual glass did not constitute over 10 to 15% of the whole, a different course of the mineral-forming process can be assumed with

certainty, and with it different conditions affecting the crystallization process of the diabase melt. Table 2 lists the principal characteristics of the facies composition of facing stone, which corroborate this assumption. A variant based on the standard normal molecular calculation (after P. Niggli or A.N. Zavaritskiy) is given for comparison. The crystallization conditions for a given variant are assumed to be ideal equilibrium. The characteristics given here have been obtained as a result of study of the stone material and of normal molecular calculations based on that material.

Both examples display evidence of a different course of mineral formation, related to a perceptible to very sizable shift in the boundary between the crystallization areas of pyroxene and plagioclase. Along with the substantial participation of aluminum in the formation of natural feldspars, and even to a greater extent in their synthetic production, there is a tendency for aluminum to participate in the building up of complex pyroxenes. Nevertheless, crystallization of aluminum in the sextuple coordination has not been given proper attention in leading petrologic classifications of the crystallization products of basalt magma, nor in the most common methods of normal molecular calculation of chemical analyses of rocks. This participation of aluminum in silicates is much more important than is commonly believed, especially under the non-equilibrium conditions of cooling of the principal silicate melt — the magma. Depending on the crystallization conditions, the quantitative boundary is more or less displaced between the crystallization areas of plagioclase and pyroxene, with a correspondingly greater or smaller proportion

Table 2
The phase composition of stones by the variants of mineral formation

Possible variants of mineral composition	Mineral phases			
	Plagioclases		Pyroxenes	
	Mineral characteristic (plagioclase No.)	Relative amount in %	Mineral characteristic	Relative amount in %
N	40-44	55	Diopside-hedenbergite with an isomorphous addition of $\text{CaFe}_2^{+++}\text{SiO}_6$	42-45
A	54-55	41,5	Enstatite-augite	38-43
B	75-80	26-32 ^a	Diopside-hedenbergite with a variable amount of Fe_2O_3	40-45
C	85-96	10-25	Diopside-hedenbergite with a considerable amount of isomorphous addition of $\text{CaAl}_2\text{SiO}_6$, $\text{CaFe}_2^{+++}\text{SiO}_6$ and $\text{NaAlSi}_2\text{O}_6$	65-80

^aQuantitative data for pyroxenes and plagioclases are not given in A.I. Tsvetkov's work [7]; we have derived them from normal calculation of the mineral characteristics.

Table 3

Crystallization of anorthite out of alkaline-free silicate melts, under non-equilibrium conditions (compiled from the author's petrographic study)

Nos. in Order	Objects of study	Chemical composition of melt (in %)						Principal parameters of the process of obtaining synthetic stone	Brief petrographic description of stone			Possible amount of anorthite from normal calculation (in %)	Actual anorthite content in stone (in %)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Total	Crystalline phases	Vitreous phase (residual glass)			
1	Samples from experimental work on synthetic stone castings, by the author.	42.1	14.8	17.1	—	9.6	16.6	100.0	T of melt = 1470°C Melt crystallized at 950 to 1000°C, for 3 hrs.	Crystalline sample, made up of a skeletal lattice of magnetite, with Ca-Mg-pyroxene and anorthite developed on it.	8-10; n=1.619-1.622	42.0	about 20
1a		42.1	14.8	17.1	—	9.6	16.6	100.0	T of melt = 1470°C Melt crystallized at 920 to 940°C, for 40 min.	Crystalline sample, made up of a skeletal lattice of magnetite, with Ca-Mg-pyroxene developed on it.	12-15; n=1.624-1.625	42.0	In small tablets; not over 6 or 8.
2		42.1	14.9	15.9	—	9.9	17.2	100.0	T of melt = 1400°C. Melt crystallized at 950°C, for 1 hr.	Crystalline sample, made up of pyroxene on a magnetite skeletal lattice.	Not over 10	41.1	Not observed.
3		45.1	16.2	15.3	—	8.0	14.6	100.0	T of melt = 1400°C. Melt crystallized at 820°C, for 1.5 hrs.	Crystalline sample, with the main body formed by complex pyroxene on a magnetite skeletal lattice.	Not over 10	45.3	"
4	Same	43.6	14.8	14.9	—	10.4	16.3	100.0	T of melt = 1400°C. Melt crystallized at 1400 to 800°C, for 4 hrs.	Crystalline sample, made up of pyroxene on a magnetite skeletal lattice. Some olivine and anorthite also present.	Not over 5-8	41.1	about 15 to 18
4a		43.6	14.8	14.9	—	10.4	16.3	100.0	Glass, obtained in annealing of melt; crystallized at 900 to 950°C for 3 hrs.	Sample finely crystalline, made up of pyroxene.	12-15	41.1	In rare tablets; not more than 5.
5	Type slab of a light-colored cast stone.	59.9	1.6	0.3	—	7.3	30.9	100.0	T of melt = 1450°C. Melt crystallized at 900 to 950°C, for 1 to 2 hrs., with subsequent slow cooling.	Cast stones, crystalline, made up of diopside in complex growths with β -wollastonite.	Not over 10-12	4.5-5	Generally not observed. Isolated tablets occasionally in central parts of larger casts.

		55.9	5.6	0.3	—	7.3	30.9	100.0		Crystalline sample; made up of pyroxene, diopside type, with isomorphous additions.	10—12; n=1.565 + 0.002	15.4	Not observed
6	Samples from experiments for obtaining light-colored cast stones of new compositions, under the direction of V. V. Chernyshev.								T of melt = 1400 to 1450°C. Melt crystallized at 920°C, for 1 hr.				
6a		55.9	5.6	0.3	—	7.3	30.9	100.0	T of melt = 1400 to 1450°C. Melt crystallized at 1100 to 1150°C, for 3 hrs.	Crystalline sample; made up of pyroxene, diopside type, with isomorphous additions; occasional anorthite tab-lets observed.	No less than 10	15.4	Rare tab-lets in cen-tral parts of the cast, no fewer than 5.
7		51.9	9.6	0.3	—	7.3	30.9	100.0	T of melt = 1400 to 1450°C. Melt crystallized at 900 to 920°C, for 1 hr.	Crystalline sample; made of diopside and β -wollastonite.	Not less than 15; n = 1.573 \pm 0.002	26.3	Not observed
8	Dump slag of nickel cast.	42.5	7.2	—	23.3	8.4	16.0	97.4	T of poured off melt = 1280 to 1330°C. 1 to 2 kg of slag crystallized while cooling under atmospheric conditions.	Crystalline sample; made up of ferruginous pyroxene with subor-dinate olivine.	5—8%	26.5	"
9		37.5	10.6	—	23.8	8.9	18.6	99.4	Same conditions.	Crystalline sample; made up of ferruginous pyroxene, olivine, magnetite, and a small amount of helenite.	In very small quantities	Up to 30	"
10	Slag from casting reverberatory furnace.	44.5	11.4	—	27.8	1.4	9.0	94.1	T of slag in ladling, 1260 to 1280°C. Large volume of slag crystallized under atmospheric conditions.	Crystalline sample; made up of ferruginous pyroxene and residual glass.	15—20%	35.8	"
11	Remolten slag from nickel blast furnace.	37.9	11.6	—	28.5	11.1	9.9	99.0	Melt crystallized for 16 hrs. in furnace, cooling off from 1260°C to 100°C.	Sample slightly crystalline; made up of ferruginous pyroxene, olivine, and magnetite.	Practically absent.	Up to 30-32	"

Table 4

Crystallization of anorthite out of alkaline-free silicate melts, under non-equilibrium conditions (compiled from published material)

Nos. in order	Source of data	Chemical composition of melt								
		SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Total
1 ^a	Experimental work by A.I. Tsvetkov [8] on synthesis of aluminous pyroxenes.	52,67	—	4,71	—	—	—	16,75	25,87	100,0
2		49,86	—	9,71	—	—	—	14,88	25,85	100,0
3		47,05	—	14,11	—	—	—	13,01	25,83	100,0
4		44,95	—	18,80	—	—	—	11,14	25,81	100,0
5	Experiments of A.I. Tsvetkov [9] on synthesis of augite.	42,44	3,66	4,67	—	—	—	16,60	25,63	100,0
6		43,51	7,25	9,24	—	—	—	14,62	25,38	100,0
7	Alloys of diopside and sesquioxides; C. Doelter [11].	42,4	—	4,0	18,1	3,6	—	12,3	19,6	100,0
8		40,8	—	17,1	3,7	13,8	—	5,9	18,5	100,0
9		37,0	—	7,7	25,3	2,6	—	10,6	16,8	100,0
10	Dump slag from water-jacket smelting of nickel oxide ores, described by V.I. Smirnov and N.L. Chelysheva [4].	40,27	—	3,53	—	13,36	—	9,37	17,73	84,26 ^b
11	Blast furnace slag, described by Vogt [12].	48,9	—	10,0	—	1,2	1,1	15,2	22,7	99,1
12	Acid blast furnace slag described by F. Angel [10]	44,72	—	9,54	—	1,12	6,90	9,63	28,16	100,07
13	Slag in smelting of metallic nickel in electric furnace, described by V.V. Lapin [13].	48,59	—	7,96	0,54	—	—	15,45	26,66	99,20
14	Copper smelting slag from reverberatory furnace, as described by V.V. Lapin [3].	56,52	—	12,13	—	17,18	0,11	—	10,07	96,01
15	Slag in smelting of ferrochromium in electric furnace, as described by V.V. Lapin [3].	38,07	0,22	14,62	0,28	1,12	0,31	19,16	20,26	94,04
16	Acid charcoal blast furnace slag, described by V.V. Lapin [3].	42,36	0,50	19,24	1,20	1,82	1,22	1,50	31,67	99,51
17	Remelted composite slag described by P.I. Bazhenov, V.A. Aleksandrovskiy, and N.G. Sergeyev [1].	35,60	0,69	9,32	3,01	8,21	7,31	6,21	29,27	99,62

^aA melt of this composition was obtained by us in the laboratory, it crystallized at 900 to 950°C, for one hr. No anorthite has been observed in the crystalline stone.

NOTE: Comma represents decimal point.

Table 4 Continued

Principal parameters of the process of obtaining synthetic stone	Brief petrographic description of stone		Possible amount of anorthite from normal calculation (in %)	Actual anorthite content in stone (in %)
	Crystalline phases	Vitreous phase (residual glass)		
Melt crystallized in slow cooling, from the beginning of solidification down to 1100°C, for 24-30 hrs.	Crystalline samples; made up of monoclinic pyroxene intergrown with residual glass (not over 10%).	Little Less than 10 Not over 10	12.5 25.6 37.5	Not observed. " "
The same conditions.	Crystalline sample; made up of monoclinic pyroxene; some anorthite.	Less than 10	50.0	Over 10-15
Melt crystallized in slow cooling from 1400°C to 1110°C, for 6 to 8 hours.	Crystalline samples, almost monomineralic; made up of monoclinic pyroxene of the titanium-augite type.	Over 3-5	12.6 24.8	Not observed.
	Crystalline sample; made up of augite; some magnetite observed.	Residual glass, colored by iron oxides.	11.4	Not observed.
	Crystalline sample; made up to augite; some magnetite observed.		48.5	Not observed.
	Crystalline sample; made up of augite; some magnetite and plagioclase.		28.8	Anorthite tablets formed in small amts.
T of liquid slag = 1280 to 1320°C. Crystallized in cooling under atmospheric conditions.	Crystalline sample; made up of diopside (75%) and enstatite (20%). Some magnetite present.	Less than 5	12	Not observed.
Slag crystallized while cooling off under atmospheric conditions.	Crystalline sample; made up of augite, olivine, and melilite	Not mentioned in description.	26.9	"
	Crystalline sample; made up of melilite (55%), augite, and olivine.	In small amount.	27.5	"
Slag ladled out at 1550 to 1600°C, and crystallized under atmospheric conditions.	Crystalline sample; made up of akermanite (69.4%) and forsterite (21%).	9; n of glass < 1.620	21.3	"
Slag ladled out at about 1250°C; crystallized under atmospheric conditions.	Sample made up of pyroxene and residual glass.	Refraction index $n \neq 1.548$	37.1	"
	Crystalline sample; made up of diopside with isomorphic additions (70%) and forsterite (11.1%).	Not indicated in description	32-34	"
Slag ladled out at 1500 to 1550°C and crystallized under atmospheric conditions.	Crystalline sample; made up of wollastonite; melilite, monoclinic pyroxene, and anorthite.	"	50	Observed in smaller amts.; $\gamma = 1.587$; $\alpha = 1.574$.
Slag ladled off at 1350°C and crystallized at 800°C, for 2 hrs.	Crystalline sample; made up of melilite (46%), hedenbergite (28%), and monticellite (25%).	Not mentioned	25.5	Not observed.

^bThe considerable difference between this and 100% is due to the lack of data on Ni, S, and other elements.

^cWe believe that the identification of pyroxene as pure hedenbergite is incorrect. It appears that the pyroxene contains Al_2O_3 and Fe_2O_3 .

of aluminum participating in building the crystalline lattice of pyroxene.

The shift in the boundary surface between the crystallization areas of pyroxene and plagioclase, at the emergence of a variable portion of aluminum in quadruple coordination in the complex pyroxenes has been confirmed by the experimental work of many students, as well as by a petrographic study of slags and products of the stone casting industry. Tabulated below is a part of that data, including the results of our own study. In order to obtain a clearer picture, and to simplify somewhat the representation of the complex crystallization process, in a multicomponent medium, only the crystallization data on alkaline-free silicate melts are given in Tables 3 and 4. For such objects of study, the position of the boundary between the pyroxene and plagioclase crystallization areas is expressed in the relative amount of anorthite in the mineral end product.

Given in Tables 3 and 4, along with the chemical composition of the crystallizing melt and with a brief description of the conditions of formation for a stone with its petrographic description are the possible quantities of anorthite obtained in normal molecular calculations for the type crystallization schemes, under conditions of maximum equilibrium.

The examples in Tables 3 and 4 lead to the conclusion that differences in the mineral formation process, brought about by different manifestations of aluminum in silicates, are expressed in the following ways:

1. In the shift of the boundary between the areas of crystallization of pyroxene and plagioclase;

2. In a change in chemical composition of pyroxene with the emergence of a variable amount of aluminum in the quadruple coordination, especially under more abruptly changing and less stable equilibrium cooling conditions for the crystallizing stone;

3. In a different degree of chemical differentiation in the formation of minerals; with the tendency for a more monomineralic nature, under conditions of greater non-equilibrium in the crystallization process.

In the crystallization of the Omega diabase melt (Example 2), the difference in the course of mineralization also was reflected in the nature (No.) of plagioclase obtained in the fixation of non-equilibrium phase ratios in the albite-anorthite solid solution series. Such differences in the mineral forming process are substantiated by voluminous experimental material, but they are the subject of a

separate communication.

In conclusion, we submit that the special effect of aluminum, which predetermines possible diversity in the mineral forming processes in basic silicate melts, should find its recognition in petrologic classifications and be taken into account in geochemical calculations.

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DETERMINATION OF STRONTIUM IN MINERALS AND ROCKS BY THE FLAME PHOTOMETRIC METHOD¹

by

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This paper describes a rapid and precise method of strontium determination in minerals and rocks with a flame photometer developed by the authors. Measurements were done on the 4607.3 Angstrom unit strontium line. A high dispersion spectrograph was used to reduce the flame background, with radioactive tracer used in order to reduce the measurement errors arising from strontium loss in chemical processing of samples. The precision of mass determinations was 5 to 6%.

* * * * *

The great interest in the chemistry of strontium prompts a search for rapid and reliable methods for its determination. Chemical methods are rather unreliable in this case and take up a lot of time because of difficulties connected with the isolation of strontium from associated calcium in most samples.

Flame photometry has been widely used for identifying strontium in the presence of calcium [4, 5, 6, 7, 9]. This work is an attempt at a strontium determination method, equally effective for both large and small amounts in mineral and rocks.

THE APPARATUS

A diagram of our installation is given in Figure 1. A solution in crucible (1) is sucked in by atomizer (2) operated by compressed air from piston compressor (3); it is fed in an atomized state into mixing chamber (4) where small drops are separated from the large ones. The latter drop out of the air stream and are gathered in a hydraulic trap; the excess liquid is poured out as it accumulates. Gas is introduced into the chamber from the line, by means of a control valve (5), and mixes with air and the atomized solution. The mixture then proceeds to the fine separation chamber where further falling out of large drops takes place.

From the separation chamber, the mixture proceeds to burner (7), with an injector (8)

installed in the center of it. Oxygen is fed in through the central nipple (9) of the injector. Because of the pressure drop, caused by the oxygen jet, some of the gas mixture is drawn into the injector from the burner. A gas-oxygen mixture is formed in the injector and comes out through a nipple (10). Gas mixture not drawn into the injector comes out of the burner through a fine mesh (11).

This method of introducing the solution under study into the flame, and of burning the gas, has certain advantages.

In analyzing solutions for their concentration of lithium, potassium, sodium, cesium, and rubidium, oxygen is not introduced into the burner because these elements react readily in a gas-air flame.

In determining the strontium and calcium content in solutions, an excess of gas is introduced into the mixing chamber, and oxygen is fed to the burner. A virtually gas-oxygen flame is then formed at the injector's orifice, in which atoms of strontium and calcium are readily excited. When oxygen is introduced into the burner, the flame acquires a typical structure: a luminous cone, diameter about 5 millimeters and about 50 millimeters high, appears in the center of a high cone of flame, of a diameter of about 20 millimeters.

Light from the inside cone is directed to the entry slit of a tripismatic spectrograph ISP-51, with an autocollimation camera UF-85. An exit slit is set up in the camera's focal plane, with a device to control the position of the slit in such a way as to have the required spectrum line completely framed in it. The width of the exit slit can be regulated by

¹ Opredeleniye strontsiya v mineralakh i porodakh metodom plamennoy fotometrii.

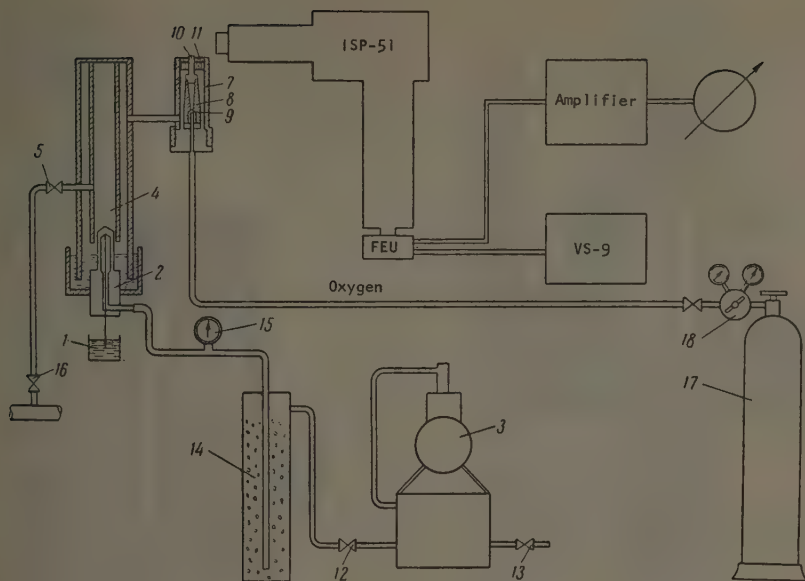


FIGURE 1. Diagram of a flame photometer.

means of a thickness gage; in our experiment, it was 0.2 millimeter. Behind the exit slit, there is a photo-multiplier FEU-19 (spectrum sensitivity range 3,500 to 6,000 Å), or else FEU-22 (spectrum sensitivity range 4,000 to 10,000 Å), depending on the length of wave whose intensity is to be determined. Voltage at the multiplier outlet is raised by a DC amplifier and is measured by a dial-and hand device.

Feeding the compressed air. Air was fed to the atomizer by a compressor used for the teeth-prosthetic soldering torch of the Kiev Copper Equipment Plant. From the compressor, the air passes through a valve (12) to an absorbent cotton filter (14) where it is cleared of water and oil drops. Excess air is vented out through valve (13). The air pressure in the atomizer is controlled by gage (15).

Feeding the gas. Gas comes from the municipal line. Precise measuring out of the volume of gas entering the mixing chamber is done by a needle valve (5). The apparatus is disconnected from the main gas line by a shut-off valve (16). A gas tank is not used in this installation, because of the small fluctuations in gas pressure during the day.

Atomizer, mixing chamber, burner. The atomizer which we used in this installation is similar to that described by I.G. Gurevich

and Ye.I. Khanayev [2]. Our model was slightly more complicated because of the changes we had introduced to reduce the flow of air and solution through the atomizer (Fig. 2) and to facilitate control.

To prevent corrosion, the mixing chamber (shown in Fig. 1) is made of plastic glass. The atomizer is fitted to the lower part of the chamber. The diameter of the outer tube is 50 millimeters, that of the inner tube is 35 mm, and the length is 250 mm. The junction of the chamber and the atomizer is made air-tight by means of a hydraulic seal formed by the atomizer's body and the lower part of the mixing chamber.

The burner is manufactured of stainless steel; a diagram of it is given in Figure 3.

Oxygen flows from balloon (17) through an oxygen reducer; it enters the lower part of the burner through tubing (1) (Fig. 3) and comes out in a jet from the injector's orifice (2). The pressure drop created in injector (3) by the jet action draws some of the gas-air mixture which arrives at the burner from the mixing chamber, through tubing (4). A complete mixing of the gas-air mixture and oxygen takes place in the injector channel. That portion of the mixture which does not get into the injector leaves the burner through a mesh (6) and burns out around the central tongue of flame.

Spectrograph; measuring the intensity of

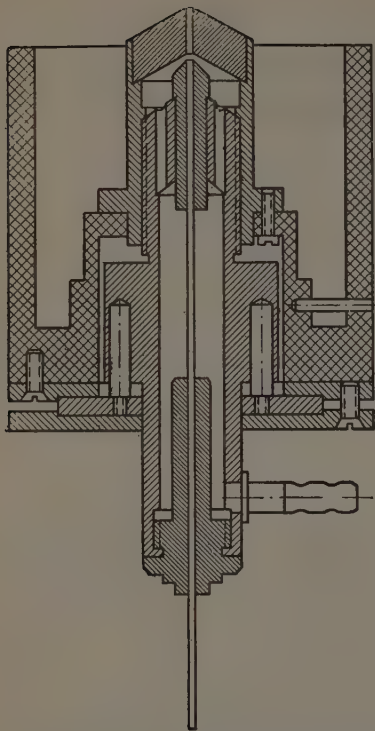


FIGURE 2. Atomizer

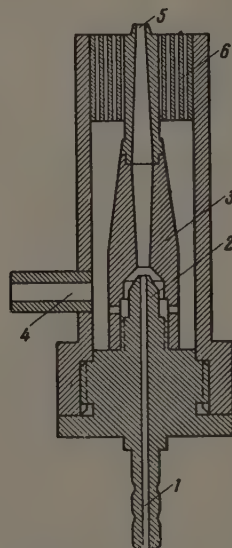


FIGURE 3. Burner

The necessity of using a high dispersion spectrograph is obvious, considering the intensity of the spectrum interval about the 4607.3 Å line, as determined with monochromator UM-2 and the spectrograph. In both cases, the solution concentration was 5.6 mg/liter.

spectrum lines. In strontium determination, we used the ISP-51 triprismatic glass spectrograph equipped with collimator, focal distance 304 millimeters, and a UF-85 camera with a focal distance of 1,300 millimeters. The spectrograph adapter was replaced with an attachment allowing the installation of an exit slit with adjusting device and a photo-multiplier.

In determining the intensity of the 4607.3 Å line, we used a FEU-19 multiplier, with a high sensitivity in that range [5].

Power is fed to the multiplier's electrodes from a VS-9 stabilized source. The multiplier's voltage is raised by a DC amplifier with a 6N-7 tube. The amplifier circuit includes a number of units allowing a damping of signals arriving from the multiplier, in order to raise the precision of measurement. In addition, provision is made for compensating the current induced in the multiplier by the flame background, and for modifying the sensitivity of the multiplier in a broad range.

The intensity ratio of the strontium line to the background did not exceed 0.3 with the use of a monochromator; for a higher dispersion of the spectrum installation — when a spectrograph was used — it was close to 3. The spectrum intensity about line 4607.3 Å is shown in Figure 4 (a) with monochromator; (b) with spectrograph.

INTENSITY OF STRONTIUM SPECTRUM LINE

The intensity of strontium line 4607.3 Å as a function of the solution concentration is expressed by a straight line, for strontium concentrations up to 100 mg/liter.

Many students [2, 4, 5] have noted that the presence of a number of substances in the flame affects the strontium spectrum intensity. To determine this effect, we introduced into the gas-oxygen flame solutions which contained, along with strontium, some other elements present in rocks in considerable amounts.

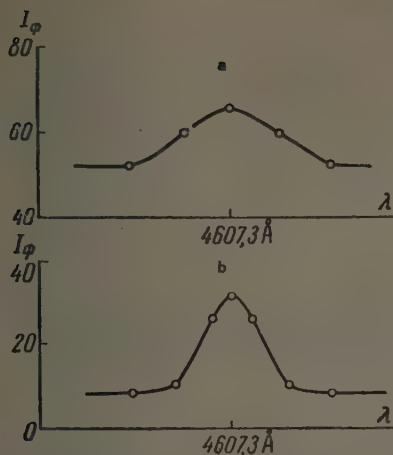


FIGURE 4. A segment of spectrum near the 4607.3 Å strontium line, obtained by: a) UM-2 monochromator; b) ISP-51 spectrograph.

Figure 5 shows a typical relation of the intensity of the strontium line to the sodium concentration; this intensity increases with the sodium content in a solution. However, the increase ceases when the sodium content has reached a certain considerable figure.

The presence of trivalent iron in a solution

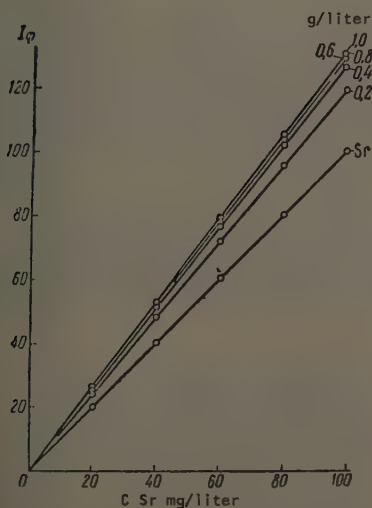


FIGURE 5. Effect of Na on the intensity of strontium line 4607.3 Å.

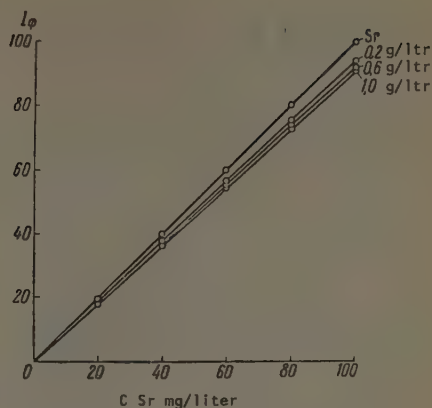


FIGURE 6. Effect of Fe on the intensity of strontium line 4607.3 Å.

reduces the intensity of its strontium line (Fig. 6); this intensity is particularly reduced, as noted by some students [5], in the presence of aluminum; it is 20 times lower when 1 g/ltr aluminum is present in solution.

The results which we have obtained in determining the effect of various metals on the intensity of the strontium spectrum in a gas-oxygen flame are given in Figure 7. We used only chemically pure chloride solutions of those metals, because a number of authors

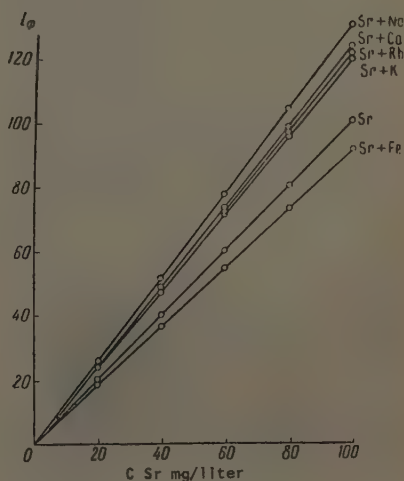


FIGURE 7. Effect of excess of K, Na, Rb, Ca, Fe (1 g/liter) on strontium line 4607.3 Å.

have noted that the presence of anions of various acids strongly affects the intensity of the strontium spectrum [5, 8].

The transfer of a rock or a mineral into solution was done in such a way as to obtain only chlorides of strontium and the associated interfering elements.

In determining small amounts of strontium, it may become necessary to operate with solutions where the calcium concentration is tens of times higher than that of strontium. In order to reduce the effect of variable amounts of calcium on the intensity of the strontium spectrum in a flame, the solution under study is augmented by an excess of sodium chloride.

We checked experimentally the effect of variable amounts of calcium on the intensity of strontium line 4607.3 Å, in the presence of excess sodium. Our study has shown that less than one gram per liter of calcium in solution increases the error in measurement 2%. To eliminate this error, the strontium concentration in a solution, in the presence of excess calcium, can be measured; in that event, however, it is necessary to check the calcium chloride for contamination by strontium.

PROCESSING OF SAMPLES FOR ANALYSES WITH A FLAME PHOTOMETER

Prior to photometering, the sample was fused with a mixture of sodium and potassium carbonates in a platinum crucible, or with caustic soda, in an iron crucible [1]. The melt was then leached out, the carbonate sediment was dissolved in hydrochloric acid, and a group of sesquioxides was precipitated out of solution by distilled ammonia. The solution was then evaporated dry in a platinum crucible and the residue was heated to eliminate the ammonia salts. The final residue was dissolved in distilled water and transferred to a measuring flask, with an addition of sodium chloride in the proportion of 3 g NaCl to a liter of solution.

We used radioactive Sr⁸⁹ [3], to check the elimination of strontium from samples. The loss of strontium was determined by the amount of Sr⁸⁹ introduced into the crucible set aside for the fusing of a sample.

The same amount of Sr⁸⁹ was placed in the measuring flask with a capacity of 25 or 50 milliliters (depending on the number of samples to be analyzed), which then was filled with distilled water. A solution so prepared was the activity standard. After the sample had been decomposed and precipitated, the sesquioxide solution so obtained was concentrated by evaporation and transferred to a

Table 1

SrO content in sample 105, in %			Loss of strontium in %
Determined with flame photometer	Loss of Sr determined by radio-active tracer	Overall content	
0.0075	0.0015	0.009	17
0.0067	0.0018	0.0085	21

measuring flask. This solution was used in determining the concentration of strontium with a flame photometer, after the addition to it of a corresponding amount of sodium chloride.

A portion of this solution, 1 ml., was poured into a measuring glass where its activity was determined with the type B-2 radiometer. After the activity of the solution prepared for photometering had been determined the measuring glass was carefully washed (to eliminate all traces of activity), dried, and then filled with the activity standard solution. After the activity determination of the standard, the proportion of strontium lost was calculated from the ratio of concentration of active strontium in solution to the activity of the solution. The accuracy of this assumption was checked experimentally, and the deviations did not exceed 5%.

Table 1 lists the result of two parallel determinations of strontium in a sample decomposed by fusing with caustic soda, while Table 2 gives the amount of strontium in the same sample but decomposed by fusing with carbonates of sodium and potassium. The results of comparison of different methods of sample processing for the strontium determination with the flame photometer have shown that any of these methods can be applied in the analysis of strontium-bearing minerals and rocks.

The considerable loss of strontium during determination in samples containing small amounts (less than 0.1%) renders a determination without the introduction of a radioactive tracer, rather unreliable. The application of

Table 2

SrO content in sample 105, in %			Loss of strontium in %
Determined with flame photometer	Loss of Sr determined by radio-active tracer	Overall content	
0.0059	0.0033	0.0092	36
0.0069	0.0019	0.0088	22

a radioactive tracer may lower considerably the determination error, reducing it to 5 or 6%.

To compare the results of strontium determination when its content in rocks and minerals exceeds 0.1%, we performed control analyses of different portions of the same sample. The results are given in Table 3.

Table 3

Samples	Weight in grams	Overall content	Deviation from average content, in %
Sample 12470	0.15	0.33	0.92
	0.25	0.33	0.92
	0.38	0.32	2.15
Euclite	0.27	0.63	0.00
	0.20	0.64	1.60
	0.25	0.62	1.60

It appears from the table that the divergence between parallel determinations does not exceed 3%.

Sesquioxides must be reprecipitated in the processing of a sample for flame photometer analysis, because when strontium is precipitated along with them, the results of an analysis may be considerably depressed. Data from two samples are given in Table 4, as an example.

Table 4

Samples	Amount of strontium, in per cent	
	Without reprecipitation	With reprecipitation
Eudialyte	0.20	0.44
Sample 12470	0.13	0.33

Determination of strontium in samples with a high strontium content presents no special difficulties.

THE MEASURING TECHNIQUE FOR FLAME PHOTOMETER

In order to eliminate the effect of variable amounts of calcium in solutions to be analyzed, 3 grams to one liter sodium chloride is added to them. The same amount of calcium chloride is added to the standard solution. The measurement of the strontium

concentration in a solution is done by comparing the deviation of the dial's hand caused by the solution in question with that caused by the standard solution.

To raise the precision of measurement, the solution in question is compared with two standard solutions, with strontium concentrations correspondingly lower and higher than in the given solution.

SUMMARY

A method of strontium determination with a flame photometer has been developed. In identifying small amounts of strontium, radioactive Sr^{89} was used to determine its losses in the chemical processing of a sample for analysis. The radioactive tracer may be dispensed with, for samples with over 0.1% strontium. To eliminate the effect of variable amounts of calcium in solutions to be analyzed, 3 g to one liter sodium chloride was added to the standards and solutions. The precision of this method in determining a strontium content of about 0.01% is 5 to 6%.

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THE USE OF GLAUCONITE IN DETERMINING THE ABSOLUTE AGE OF SEDIMENTARY ROCKS BY THE ARGON METHOD¹

by

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A. L. Khutsaidze, and O. Ya. Gel'man

In view of the useful results obtained from using the argon method to determine the absolute age of micas, we suggested in 1955 [10, 11] that a very common authigenic mineral, glauconite, which closely resembles mica in structure, might retain radiogenic argon and that it was therefore theoretically possible to use the argon method for dating sedimentary rocks.

This hypothesis was then verified by us in the Dagestan Branch Laboratory of the U.S.S.R. Academy of Sciences using Cenomanian glauconite from the neighborhood of Kutaisi, and also, at our request, by Ye. A. Gerling in the Laboratory of Precambrian Geology of the U.S.S.R. Academy of Sciences, using Silurian glauconite from Estonia. These tests yielded the first figures demonstrating the necessity for continuing research in this direction [12]. Further work was allocated to the Dagestan Branch of the U.S.S.R. Academy of Sciences [1]. Then the results of similar research done abroad were published [15, 16]. Kazakov and Poleyaya [7] also undertook a further study on the use of glauconite for geochronologic purposes.

The material so far published seems to justify the belief that glauconite is a promising subject for geochronologic research, for there are already a good many figures, covering a wide range in time — from the earliest Paleozoic to the Lower Miocene, inclusive — indicating satisfactory coincidence of data indicating the absolute age of the glauconite with the age of their enclosing deposits as determined by conventional biostratigraphic methods.

On the other hand, although the Kazakov-Poleyaya paper [7] contains information on 22 specimens of glauconite which have more or less satisfactorily retained radiogenic argon, Amirkhanov et al [1] note that of 45 glauconite specimens for which age determinations

were made, only 26 measurements, or about 58 per cent, gave full correspondence with the geologic data, in 8 cases "rejuvenation" of the glauconite was observed — that is, the loss of part of the radiogenic argon — while in 11 specimens they failed to detect any radiogenic argon at all. Unfortunately, these authors merely note the fact that some of the glauconite showed argon losses, without giving any information on the amount of the partial argon losses or on the geologic position and mineralogic characteristics of the glauconite specimens which had lost some or all of their radiogenic argon. Moreover, it is not clear what "defects in the procedure of preparing the specimens for the determinations" mentioned by the authors, could have led to partial argon losses in some cases.

As a result of their discovery of argon losses by the glauconite, Amirkhanov et al later [2] specifically investigated the relationship between the amount of radiogenic argon released from glauconite during preheating and because of the heating temperature. They determined that if glauconite was heated for eight or ten hours even at 100°C it lost approximately 20 per cent of its radiogenic argon, but towards 500°C total argon release occurred. Comparing these figures with the typical glauconite thermograms given in the literature [14], these authors came to the conclusion that the loss to the glauconite of adsorbed water apparently entailed a loss of 20 per cent of the argon, while the release of water of constitution led to the loss of all the remaining argon.

We did not find it possible to take these results into account, in the first place, because if it were really characteristic of glauconite to lose a considerable amount of argon at a temperature of only 100°C, it would be highly unlikely that all the radiogenic argon accumulated in the course of its existence could have been retained, especially if the glauconite formed under geosynclinal conditions. Furthermore, such an inference is not in line with the fairly numerous figures indicating comparatively good argon retention in glauconite.

¹ K ispol'zovaniyu glaukonita dlya opredeleniya absolutnogo vozrasta osadochnykh porod argonovym metodom.

There is another important point. The radiogenic argon content in the glauconite referred to by Amirkhanov et al [2], under the heading "Estonian" is given as $0.165 \text{ mm}^3 \text{ (ntp)}$. This specimen, which the authors in due course handed over to us, contains 6.46 per cent K, so that its age must be about 575 million years ($\lambda K = 0.557 \times 10^{-10} \text{ yr}^{-1}$, $\lambda \beta = 4.72 \times 10^{-10} \text{ yr}^{-1}$ and $K^{40} = 1.22 \times 10^{-4} \text{ K g/g}$) — not what we should expect for an Ordovician mineral. We therefore set up a series of tests on the same glauconite in order to verify the published data experimentally.

The material studied, which was kindly provided by Kh.G. Pal'mre, was taken from the Tallin horizon in the Maardu phosphate mine.

The monomineral fraction of the glauconite was extracted in our laboratory in electro-magnetic and electrostatic separators [13]. The screen was checked for cleanness under a binocular microscope. The glauconite was represented by dark-green grains, 0.1 to 0.5 mm in diameter; $\gamma = 1.609 \pm 0.002$; $\alpha = 1.603 \pm 0.002$. The chemical analysis data are given in Table 1.

Table 1
Chemical composition of Tallinn glauconite

Oxides	Weight per cent	Oxides	Weight per cent
SiO ₂	50.24	CaO	0.59
TiO ₂	none	K ₂ O	7.78
Al ₂ O ₃	3.65	Na ₂ O	0.32
Fe ₂ O ₃	22.67	P ₂ O ₅	1.26
FeO	2.99	SO ₃	none
MnO	none	H ₂ O	2.68
MgO	4.68	other	2.94
		Total	99.80

NOTE: Comma represents decimal point.

The radiogenic argon content in the specimens was determined by the mass spectrometry method of isotopic dilution, atmospheric argon being taken as the standard, as suggested by I.G. Gurevich and described by Amirkhanov et al [3]. Special care was taken to establish the margin of error in the measurements.

It was found that the radiogenic argon

content in a glauconite specimen which had not been preheated was 0.130 ± 0.001 (mean of six determinations). This corresponds to an age of about 465 ± 10 million years. Weighed portions of the specimen were then heated for eight hours in a crucible furnace at 150° , 300° , 400° , 500° , 600° and 700°C , after which the residue of radiogenic argon in the specimens was measured. Table 2 gives the measurement results, together with the figures obtained by Amirkhanov et al [2] for purposes of comparison.

As can be seen from this table, the figure of $0.165 \text{ mm}^3/\text{g(ntp)}$ should, it seems, be regarded as erroneous, and up to 400°C the glauconite does not suffer any considerable loss of argon, over and above the margin of measurement error, but the specimen which has been preheated to 500°C loses some two thirds of its radiogenic argon, while at 600°C it loses nearly all the radiogenic argon. These results are close to those obtained by G.A. Murinaya and quoted by Kazakov and Polevaya [7], although they also differ from the latter in that according to Murinaya the argon release starts at 300° and reaches its maximum at 400°C .

It must be noted that apparently by no means all the argon capable of being released from the glauconite at a given temperature is in fact extracted in the course of eight hours heating. This is shown by the results we obtained in determining the residual argon in glauconite heated to 500°C for 40 hours: we found that only $0.003 \text{ mm}^3/\text{g (ntp)}$ of A^{40} remained. In other words, heating at 500°C for 40 hours was equivalent, in terms of argon extraction, to heating at 600°C for 8 hours.

There are, accordingly, some grounds for supposing that if glauconite is heated for a sufficient length of time to a temperature at which it is possible for a considerable amount of argon to be released, this process can lead to complete loss of argon by the mineral. This hypothesis requires verification by further experiments.

Such research would be of interest partly in order to discover the nature of the actual process by which argon is released from the minerals and partly also for purposes of paleothermometry, as Amirkhanov and his co-authors [2] have already remarked.

The Debye crystallograms of our glauconite taken by G.V. Tsintsadze for specimens which had not been heated and for specimens heated for 8 hours at 500°C (Table 3) proved to be similar to one another, indicating that the argon release occurs before the crystal lattice of the glauconite starts to break up. Amirkhanov and co-authors had already reached a

Table 2
Radiogenic argon content in Tallinn glauconite

Our measurements			Data of Amirkhanov et al [2]		
Weight of portion, g	t of preheating in air for 8 hours	Amount of residual Ar ⁴⁰ , mm ³ /g (ntp)	Weight of portion, g	t of preheating in air for 8 hours	Amount of residual Ar ⁴⁰ , mm ³ /g (ntp)
5,0	before heating	0,130±0,001 ^a		before heating	0,165
5,0	150	0,130±0,006 ^b	2	100	0,131
8,3	300	0,126±0,005	2	200	0,129
9,3	400	0,124±0,013	2	300	≈0,129 ^c
8,0	500	0,047±0,004	2	400	0,118
9,0	600	0,003±0,001	2	500	0,000
			2	600	0,000

^aMean of 6 measurements. ^bMean of 3 measurements. ^cCorrected according to graph [2].

NOTE: Comma represents decimal point.

similar conclusion [2]. Lazarenko [8] also points out that no substantial modifications occur in the X-rays of glauconite preheated to 700°C.

If we compare the glauconite thermogram taken by the present authors, which showed the first endothermic effect as occurring in the interval between 160 and 280°C and the beginning of the second at around 600°C, with the course of argon release from the glauconite, we find no indication of a direct connection between the latter process and these thermal effects. There is nothing

surprising in this; muscovite behaves similarly, the first endothermal effect being observed within the interval between 780 and 1,000°C [14], whereas the argon release, according to Gerling's data [6] begins above 600°C.

To determine the amount of residual argon in glauconite specimens which had been preheated to various temperatures we measured the refractive indices. These are shown in Table 4.

As the table shows, the refractive indices in general become higher as the preheating

Table 3
Data from Debye crystallograms of Tallinn glauconite

Number of line	Not preheated		Preheated at 500°C for 8 hours		Number of line	Not preheated		Preheated at 500°C for 8 hours	
	<i>l</i>	$\frac{d}{n}$	<i>l</i>	$\frac{d}{n}$		<i>l</i>	$\frac{d}{n}$	<i>l</i>	$\frac{d}{n}$
1	3	4,648	—	—	12	3	2,263	1	2,275
2	—	—	4	4,596	13	3	2,127	1	2,154
3	1	4,436	—	—	14	3	1,977	2	2,008
4	—	—	3	3,768	15	2	1,814	1	1,804
5	4	3,707	—	—	16	1	1,714	3	1,739
6	4	3,317	4	3,336	17	5	1,660	2	1,644
7	4	3,082	3	3,091	18	2	1,585	1/2	1,579
8	—	—	1	2,901	19	1	1,529	—	—
9	2	2,689	—	—	20	10	1,508	10	1,514
10	10	2,581	10	2,622	21	—	—	1	1,445
11	9	2,403	8	2,434	22	—	—	1	1,323
					23	9	1,299	8	1,304

Table 4

Refractive indices of Tallinn glauconite

Heating	γ ($\pm 0,002$)	α ($\pm 0,002$)
Not preheated	1,609	1,603
Preheated at 200° (8 hours)	1,617	1,611
" " 300 " "	1,632	1,622
" " 400 " "	1,634	1,624
" " 500 " "	1,639	1,630
" " 500 (40 hours)	1,638	1,630
" " 600 (8 hours)	1,644	1,638
" " 700 " "	1,641	1,637

NOTE: Comma represents decimal point.

temperature is raised, the color of the glauconite changing from green to reddish brown, while there is a sharp rise in the refractive indices between 200° and 300°C. It looks as though this effect might be connected with the release of water of adsorption from the glauconite, since the first endothermal effect appears on our thermogram within precisely this interval. Lazarenko, however [8], observed a similar discontinuity, in two glauconite specimens which he studied, at a somewhat higher temperature interval (between 300° and 350°C), whereas the thermograms of these glauconite specimens given in his paper show the first endothermal effect as occurring at a temperature as low as 100°C. The question accordingly remains open.

It would be worth discovering how far this change in the refractive indices of glauconite is constant and independent both of subsequent lowering of temperature and of other conditions. We have already set up the prolonged experiments required for such verification, and should the variation prove stable it may well be that the refractive indices of glauconite have the peculiar quality of indicating the particular thermal history of these minerals and, consequently, their suitability for purposes of absolute dating and paleothermometry.

A reservation, however, must be made: the relationship in question seems to be rather complicated, for according to published data [5, 8], the rise in the refractive indices of glauconite depends largely on the iron content in the mineral; however, the glauconite we studied would appear to be an exception to this rule, for while the iron content was high, the refractive indices were comparatively low.

The suitability of glauconite for purposes of absolute geochronology cannot be assessed without reference to the potassium retention

in the lattice of this mineral. Amirkhanov et al, in the paper we have mentioned several times above [2], refer to experiments by Grüner, who showed that in glauconite boiled for four hours in a solution of thallium nitrate, 25 per cent of the potassium was replaced by thallium, whereas no such substitution was observed in the case of biotite. Moreover, a well-known experiment in using glauconite as a base for cation exchange [4, 9] arouses some caution. Nevertheless, a four-hour boiling of our glauconite both in distilled water and in an aqueous solution of NaCl, KCl, MgCl₂ and CaCl₂ corresponding to sea water as regards cation ratios and overall concentration of salts revealed no significant variation in the potassium content of the specimen studied. These crude preliminary experiments are, of course, quite inadequate for any convincing assessment of the migration capacity of the potassium contained in the crystal lattice of glauconite, but in view of all the circumstances there does not seem to be any special reason for fearing that glauconite under natural conditions is capable of readily losing its potassium.

The above factual material from a study of Tallinn glauconite cannot, of course, be regarded as exhaustive or sufficient for an unqualified assessment of glauconite as suitable for purposes of absolute geochronology. Even apart from the points mentioned above, and apart also from the necessity of discovering the influence of preheating at low temperatures but for a long period on the argon retention in glauconite, studies of this kind must be performed on glauconite specimens varying in their properties, and in particular on glauconite formed both under platform and other geosynclinal conditions.

Nor is this all. The argon retentivity of glauconite has so far been assessed on the basis of the more or less good agreement

between the age figures obtained in biostratigraphically dated glauconite and the data from existing geochronologic scales. Such an approach was natural in the first stage of the research; but since it is quite obvious that the existing scales are incomplete, it could well be that in a number of cases the fact that the figures obtained from the glauconite fit some interval in these scales is no indication that argon has been fully retained in the specimens measured.

For this reason we regard it as urgent to compare glauconite with synchronous micas over as wide a range of geologic time as possible. It will not be so easy to select the micas required for such comparison, in view of the comparative rarity of intrusives squeezed within narrow age limits. It might perhaps be easier to select stratified extrusives and primary pyroclastic formations rich in biotite.

In regards to this question, the results we obtained on a biotite of the Kelasur granitoid intrusion deserve attention. This intrusion intersects a Bajocian porphyritic stratum and transgressively overlaps the Neocomian. According to some findings, boulder rocks of this intrusion are found in a varicolored stratum of Kimeridgian tinton. These facts, taken in conjunction with the importance of the Bathonian orogenic phase in forming the structural shape of Transcaucasia, indicate that the Kelasur intrusive is most probably of Bathonian origin.

The A^{40} content in this intrusive is $0.0410 \pm 0.0016 \text{ mm}^3/\text{g}$ (ntp) and the potassium content $6.175 \pm 0.061\%$. The A^{40}/K^{40} ratio is 0.00996 ± 0.00058 , which corresponds to an age of 167 ± 9 million years if we accept the constants mentioned above; so unless the biotite of the Kelasur intrusion is, for some reason still unknown to us, an anomaly, substantial changes should be introduced into the geologic time chart for the Mesozoic.

Generally speaking, the estimate of 25 million years as roughly the duration of the Jurassic, without reference to the figures for the Kelasur biotite, arouses considerable doubt; in particular, the paleontologic information does not fit in well with the existing scales for the Cretaceous period, which is given as lasting three times as long as the Jurassic.

Our figures for the Kelasur biotite can be further verified from biotite of the Khevis-Dzhvar granodioritic intrusive (Dzirul'sk masif), which also intersects the Bajocian and is overlapped by the Lower Cretaceous. If it should really prove necessary to introduce significant changes in the absolute dating of the Mesozoic, the age figures for the corre-

sponding glauconite, which at present seem to us sufficiently satisfactory, will also have to be changed.

Summarizing the above, we conclude that although the study of glauconite as material for determining the absolute age of sedimentary rocks has already yielded a good many encouraging results, these must not yet be regarded as exhaustive. Experimental and methodical research in this direction must be continued and expanded; hasty attempts at compiling geochronologic charts from glauconite data are fraught with the risk of producing premature, insufficiently well-based conclusions.

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BRIEF COMMUNICATIONS

NEW DATA ON AGE OF THE CHERNYSHEV RIDGE BASALTS IN NORTHEASTERN AREAS AND THE PECHORA BASIN¹

by

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Basalts of Chernyshev Ridge are known from works of A. V. Zhuravskiy [2], N. A. Kulik [4], A. A. Chernov, [9] and O. L. Eynor [12, 13] who studied the Permian section along Adz'va River where the largest basalt body is exposed (Talbay cliff, point 1 on map). Early views on the age of these basalts were voiced by N. A. Kulik who believed them to be upper Paleozoic ("Permian, perhaps Triassic"). A. A. Chernov [9] believed that the basalts were poured out in the interval between the Early Kimeridgian and Santonian, basing his assumption on the absence of basalt pebbles in the near-by Lower Kimeridgian outcrops, and of disturbances in Santonian deposits east of the Chernyshev Ridge. O. L. Eynor [12, 13] found small basalt outcrops on Adz'va River (point 2 on map) where they are in contact with Jurassic deposits. Believing that these basalts cut Jurassic deposits, he assumed them to be post-Jurassic (Santonian).

In 1957, the Adz'va basalts were examined by this author who was conducting a lithologic and stratigraphic study of the Permian section there [7]. These 1957 observations (in cooperation with L. A. Anishchenko) provide a basis for modifying our ideas on the age of the Chernyshev Ridge basalts and for refining the dating of basalt from the northeastern Pechora basin.

The main argument for a post-Jurassic age of the Chernyshev Ridge basalts was the above-mentioned data of O. L. Eynor. Our

observations have revealed the error of O. L. Eynor's view [12, 13] on an intrusive character of the basalt contact with Jurassic deposits along the Adz'va. In that exposure (point 2 on map), the base of Jurassic deposits,² resting on an uneven surface of basalt, carries fragments of the underlying material; similar fragments have been observed in sandy material filling up the valves of Jurassic shells. These facts suggest that Jurassic deposits rest on the basalt with an erosional break.

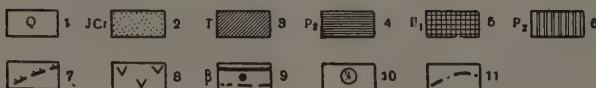
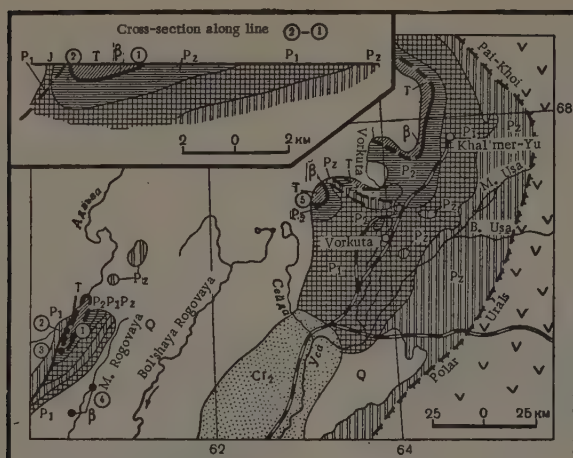
Jurassic deposits, preserved from erosion in hollows of the uneven basalt surface were erroneously taken by O. L. Eynor as evidence of a basalt intrusion.

Let us turn now to a basalt exposure along the Adz'va, where they form the Talbey Cliff (point 1 on map). Here, the basalts are overlain by the upper Permian Pechora series of interbedded sandstone, siltstone, shale, and coal beds. The visible thickness of basalt is 25 to 30 meters, with the overlying rocks not exposed. Along a 1.5 kilometer stretch of the right bank, the base of basalt is seen to run parallel to the bedding of the underlying sequence (dipping northwest, at 10 to 15°). At two points (one kilometer apart) basalt is in direct contact with the underlying rocks, the same thin (3 to 6 meters) member of motley rocks capping a coal-bearing sequence. These facts point to the conformable between the basalts and the underlying rocks. We shall bring forth additional evidence for the conformable position of basalts on Permian beds, in folded structures of the Chernyshev Ridge, after we have considered the stratigraphic position of basalt in the Talbey Cliff.

A sequence (over 150 meters thick) underlying the Talbey Cliff basalt was assigned by O. L. Eynor [12, 13] to the epi-coal measure

¹Novyye dannyye o vozraste bazalt'ov gryady Chernysheva i Severo-Vostochnykh rayonov Pechorskogo basseyna.

²Jurassic deposits are almost horizontal, resting with a sharp angular unconformity on disturbed Paleozoic and Triassic rocks.



Generalized geologic map of northeastern Pechora basin.

- 1 -- Quaternary deposits; 2 -- Jurassic and Cretaceous deposits; 3 -- Triassic; 4 -- Upper Permian; 5 -- Lower Permian; 6 -- Pre-Permian Paleozoic deposits; 7 -- boundaries of Central Urals and Pai-Khoi; 8 -- Central Urals and Pai-Khoi; 9 -- basalts (dashed line -- as determined by geophysics; 10 -- basalt outcrops mentioned in text; 11 -- fault traces.

Tal'mayus formation (Kheyyagin series in present nomenclature). According to our observations, it belongs to the Pechora coal measures. This is corroborated by the presence in this sequence of coal lentils; by the lithofacies of its rocks, similar to the Pechora series; and by the similar assemblage of concretions. Its floral assemblage, too, suggests association with the Pechora series. Described from it are the following forms (by Kh. R. Dombrovskaya; asterisk refers to identification by M. D. Zaleskiy, from collections of earlier investigators): *Noeggerathia* sp., *Phylladoderma* sp., *Ph. Arberi* Zal., * *Cordaites clerici* Zal., * *Vorcutannularia plana* Pog. (in ms), *Phillotheca striata* Nub., *Sciadiscia petschorensis* Zal., *Paracalmites* sp.

An abundant fauna was found at the base of this sequence, including *Concinella buredanica* Pog. (in ms.) which is, according to V. V. Pogorevich [6], an index form for the Pechora series.

It should also be noted that the familiar and consistent criteria for the lower half of

the Kheyyagin series, in the Pechora basin area (Pai-Khoi, Vorgashor deposit, Chernyshev Ridge), namely the considerable sequence of motley beds, the absence of coal, the extreme scarcity of plant remains, the calcareous composition of concretions, etc., preclude the assigning of this unit to the Kheyyagin series.³ At the same time, some of the features of this unit, such as the sharp drop in the coal content, the impoverishment in flora, the absence of a fauna in most of the interval, and the presence of motley beds at its top, suggest its transitional character and its association with the uppermost stratigraphic interval of the Pechora series.

The author has observed a similar transitional sequence (also with motley beds) at the top of the Pechora coal measures, in southwestern Pai-Khoi, where it is overlain by red to gray Kheyyagin deposits.

³The Kheyyagin series is an epi-coal measures unit in the Pechora basin, conformable upon the Pechora series. In the northeast of the basin (see map), the two series are separated by a basalt sheet.

These facts suggest that the Talbey Cliff basalt is conformable on the topmost Pechora beds.

The joint disturbance of the Talbey basalt and the enclosing rocks became especially clear after a review of the stratigraphic position of beds exposed downstream from the Talbey Cliff. Namely, an exposure of motley beds (exp. Ch-25, described by A.A. Chernov) between the two above-mentioned basalt exposures (15 to 20 meters from point 2 on map), assigned to the Artinskian by earlier investigators [9, 12], turned out to be Kheyagin, as witness the findings of a phyllopod fauna, with *Pseudestheria gutta* Lutk., *Ps. cf. aequale* Lutk., *Asmusia petasa* Nov., etc., as identified by V.S. Zaspelova. A basalt layer has been observed at the very base of this sequence. The marine fauna which made earlier investigators assign this unit to the Lower Artinskian turned out to be reworked. It has been determined that the sequence exposed a short distance downstream (exp. Ch-24, of A.A. Chernov) belongs to the Lower Vorkutsk formation of the Vorkutsk series (Lower Permian coal measures of the Pechora basin) and is overturned.

In the light of these facts, the hitherto mysterious nature of the Talbey syncline and the position of the basalt in it have been cleared up. As shown in the cross section, the Talbey syncline is an asymmetric structure, with its northwestern limb overturned and complicated by a thrust. The youngest rocks, belonging to the Kheyagin coal measure are exposed in the center of the syncline. The two basalt outcrops between which the Kheyagin rocks are exposed are portions of the same basalt unit (underlying the Kheyagin series) located on the opposite wings of the Talbey syncline. This conclusion [7] has been fully substantiated by geophysical work undertaken by N.N. Bolgurtsev in 1958, to trace the basalt.

Thus, the Adz'va River basalts are underlain by the Pechora series, overlain by the Kheyagin series, and have been dislocated along with both.

A continuation of the Adz'va basalts is a basalt outcrop along Isak-Yu River, discovered in 1957 by Ya. Ya. Vasilenko and S.A. Knyazev (point 3 on map), and occurring (according to this geologic map) in similar stratigraphic and structural relations with Permian rocks. Basalt outcrops along Malaya Rogovaya River (point 4 on map), in an adjacent area, undoubtedly belong to the same basalt unit. Exposed here are (according to Ya. Ya. Vasilenko and S.A. Knyazev, 1957) the overlying rocks represented by a 30 to 40 meter sequence of gray to red beds belonging most probably to the epi-coal measures

Kheyagin series.

The extrusive nature of the Chernyshev Ridge basalts has been recognized by all students.⁴ Indeed they are (like basalts in the northeastern Pechora basin) amygdaloidal (olivine), with a considerable content of volcanic glass. Their extrusive character is confirmed by the presence of basalt pebbles in the overlying Kheyagin beds (along the Malaya Rogovaya, point 4 on map).

These data suggest that basalt exposures known from the Chernyshev Ridge area belong to the same basalt sheet (or else to two proximate flows) located stratigraphically between the Pechora and Kheyagin series and naturally involved in the folding of both.

There are no good reasons to doubt that the Chernyshev Ridge basalt is a continuation of a basalt sheet known from the northeastern Pechora basin [11], also associated with the Kheyagin-Pechora contact. The wide distribution of this sheet has been recognized in recent years by drilling and by geophysical work.

The age of the Pechora basin basalt is determined by that of the overlying and underlying deposits. All students assign the Pechora series to the Kazanian stage, with its upper part possibly belonging to the Tatarian. In lower beds of the Kheyagin series (above the basalt), the author has found phyllopods in borehole No. 1147 of the Vorgashorsk deposit (point 5 on map), among which V.S. Zaspelova has identified the following forms: *Pseudestheria tungusensis* Lutk., *Ps. aff. gutta* Lutk., and *Pseudoasmusia* sp.

The specific association of this phyllopod unit with the base of the Kheyagin series is corroborated by the proximity of its exposure to that of basalt, also by the presence of a basalt layer in its lower part.

These data make it possible to correlate the base of the Kheyagin series in the Pechora basin with the Vetluga stage in the Russian platform [5], also with the Korvunchan formation of the Nizhnaya Tunguska [8, 10], the Misaylapsk formation of the Nordwick-Khatanga region [10], and the Ust'-Yenisey region tuffaceous, argillaceous sequence [3], all assigned to the Lower Triassic.

Thus, the basalt flows, spreading over a considerable area in the northeast Pechora basin and in the north of Chernyshev Ridge,

⁴In assuming that the Adz'va basalts cut Jurassic deposits, O.L. Eynor [12, 13] believed this to be a local complication of the extrusive phenomenon.

were extruded at the end of the Permians. We note that this is in accordance with the assumption of N. A. Kulik (1910).

The author takes this opportunity to express his gratitude to L. A. Anishchenko, K. K. Vollosovich, A. D. Miklukho-Maklay, V. N. Gesse, and A. N. Shulepova for their inspection of samples and for their advice.

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THE GIVETIAN-FRASNIAN BOUNDARY IN BASHKIRIYA⁵

by

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Deposits of the Givetian and Frasnian stages of the Devonian of Eastern Bashkiria present a rhythmic alternation of sandy beds D-V, D-IV, D-III, D-II, D-I, and D-0; the

⁵K voprosu o granitse zhivetskogo i franskogo yarusov v Bashkirii.

"Mikhaylovskiy" unit, the intervening silty shale, and the dominantly carbonate rocks marking the "Lower Limestone," "Ardatovsk," "Middle Limestone," "Black Limestone," "Zaitovsk," "Upper Limestone," "Middle Kynov Limestone," and "Upper Kynov Limestone" [3, 4].

In the Tuymazy area, this sequence begins with light-gray quartz sandstone of unit D-V, average thickness of 5 to 7 meters. They are overlain by carbonate beds of the marker "Lower Limestone" (average thickness 8 to 10 meters) overlain conformably by a siltstone-shale member which, in turn, is replaced, upward and laterally, by sandstone and gravel of unit D-IV, 12 meters or more thick. These sandstones are overlain by a shale-siltstone member whose upper part is replaced laterally by D-III sandstone. The lower part of this member commonly carries siderite intercalations, changing locally, laterally, to limestone (the Ardatovsk datum). The thickness of this siltstone-shale member ranges here from 12 to 16 meters, with the D-III sandstone 0 to 8 meters thick. Above them there are carbonate beds of the "Middle Limestone" marker unit (average thickness about 2 meters), changing to a shale-siltstone member and replacing the uppermost D-II beds; their total thickness is 22 to 24 meters.

Sandstone of unit D-II are overlain by shale and siltstone with a marker layer of argillaceous "Black Limestone" toward the bottom. They change upward, in places, to D-I sandstone. Still higher up, some sections carry the marker "Upper Limestone," while some others have an intermediate shale-siltstone member (the Zaitovsk datum) which changes upward to D-0 sandstone [3].

The thickness of the Zaitovsk datum bed and the D-0 sandstone ranges widely, changing from 0 to 34 meters over a distance of 1.5 to 2 kilometers (the Verkhnezaitovsk, Chekmagushev, and other areas of western Bashkiria).

Carbonate rocks of the "Upper Limestone" marker horizon, average thickness 1.5 to 2 meters, change gradually to the overlying green-gray to chocolate-brown shale with siltstone intercalations. The upper beds of this member are locally replaced by the so-called "Mikhaylovsk" sandstone [4].

Some 12 to 16 meters above the base of the "Upper Limestone" there are thin carbonate lentils (about one meter thick) of the "Middle Kynov Limestone" characterized by an assemblage of unquestionably Frasnian brachiopods (of the *Cyrtospirifer murchisonianus* Vern. group and other Kynov forms).

Carbonate rocks of the "Upper Limestone" marker unit are characterized by a diversified faunal assemblage. Most important in determining the stratigraphic position of the "Upper Limestone" are brachiopods and ostracods. Most common among the brachiopods are *Atrypa pseudouralica* Nal., *A. ex. gr. tubaecostata* Paeck., and *Ilmenia tenuicosta* Mikr. Also present are *Atrypa velikaya* Nal., *A. dauvillei* Mans., *A. ex. gr. uralica* Nal., *A. ex. gr. aspera* Schl., *A. ex. gr. reticularis* Lin., *A. koloshka* Nal., *Athyris ex. gr. concentrica* Buch., *Productella ex. gr. subaculeata* Murch., *Lingula laewinsoni* Wen. (identification by M. F. Mikryukova, A. I. Lyashenko, and others).⁶

This list suggests the transitional nature of the brachiopod assemblage. The definitely Givetian deposits carry forms close or similar to many of those names above; however, the list contains forms resembling the Frasnian assemblage.

A more definite answer to the problem of the stratigraphic position of the "Upper Limestone" is provided by ostracods. This limestone carries *Uchtovia polenovae* Egor., *Tulenia aptata* Pol., *Indivisia schigrovskensis* Pol., *Gravia (selebratina) tuimazensis* Pol., and *Buregia egorovae* Pol. (identification by A. V. Vladimirova, A. A. Rozhdestvenskiy, and others).

None of these forms has been found below the "Upper Limestone," while two out of the five are common in the "Upper Limestone" and in the definitely Frasnian "Middle Kynov Limestone" (*Uchtovia polenovae* Egor. and *Tulenia aptata* Pol.).

It is to be assumed that the interval from the base of the "Upper Limestone" to the base of the "Middle Kynov Limestone" is the initial rhythm of the Frasnian stage. It corresponds to the Pashysk beds of the western Uralian slope and to the Yastrebov beds from central provinces of the Russian platform.

In their description of Devonian deposits from borehole 1/2, at the village of Ardatovka in the eastern part of the Russian platform, in 1940, V. A. Balayev [1], Ye. A. Grablin, I. D. Korzhenevskiy, M. V. Mal'tsev, I. P. Nikolayev, and A. D. Nikitin [2] drew the Givetian-Frasnian boundary at the top of the "Upper Limestone" marker unit (which was not defined at that time). This concept persisted until 1948 when M. F. Mikryukov and K. R. Timergazin [5] lowered that boundary to the base of the D-IV sandstone. Soon

⁶The frequent occurrence here of *Atrypa bashkirica* Mikr. has been mentioned. However, according to A. I. Lyashenko, that form is a young specimen of *Atrypa pseudouralica* Mikr. (Author's note).

after, however, a definite Givetian faunal assemblage was found in the overlying "Middle Limestone" marker unit, by a number of students (A. Ya. Vissarionova, M. F. Mikryukov, V. N. Tikhiy, and others). From then on, the Givetian-Frasnian boundary has been drawn on shale overlying the "Middle Limestone." It was so ruled by the 1951 Conference on the Unification of Stratigraphy of Devonian and pre-Devonian Deposits in the Russian Platform and the Western Slope of the Urals [6].

In 1954, A. A. Rozhdestvenskaya [7] recognized Givetian ostracods in the "Black Limestone." At the present time, the Givetian-Frasnian boundary in Bashkiriya is drawn on silt and shale overlying it.

As a result of a study of Devonian deposits in the Volga-Ural province, V. P. Bukhartsev — and this author, a year later — have come to the conclusion that the Givetian-Frasnian boundary should be drawn at the base of the "Upper Limestone" marker unit [3].

This conclusion is substantiated by the following facts. Paleontologic evidence suggests this boundary somewhere above silt and shale overlying the "Black Limestone" whose Givetian age has been proven unquestionably by its fauna, and below the "Upper Limestone" with its brachiopods assemblage of a transitional age and Frasnian ostracods [4].

N. G. Pykhova states that she has found a Givetian-like spore assemblage in lower D-I sand lentils of the Romashkinskiy oil field, Tatariya.

Remains of the *Pseudosporochnus krejci* P. et B. were found in a shale-siltstone member separating units D-1 and D-0 ("Zaitkovskiy" datum). According to S. M. Domrachev, this form occurs in the Middle Devonian of Czechoslovakia and along the western Uralian slopes.

The combination of D-I shale, siltstone, and sandstone represents an elementary rhythm which is an independent stratigraphic unit. This complex rests with a slight unconformity on underlying deposits. At the same time, there is a stratigraphic and angular break (up to 2°) below the "Upper Limestone" beds which rest, with or without an erosional break, either on D-1 or D-0 sandstone or on shale with siltstone separating them.

Thus the inconsistent interval from the top of shale and silt overlying the "Black Limestone" to the base of "Upper Limestone," 20 to 55 meters thick (Tuymazy Verkhne-Zaitovo, Serafimovka, Chekmagush, etc.) has

not yet been definitely dated paleontologically. On the other hand, there is a regional unconformity below the "Upper Limestone" marker beds [3]. It follows, then, that the more substantial tectonic movements, with a remodeling of the structure and a local erosion of earlier sediments, took place prior to deposition of the "Upper Limestone." This means that a Givetian-Frasnian boundary drawn on the base of the "Upper Limestone" marker unit is closer to the true boundary, in terms of fitting of correspondence of stratigraphic boundaries with stages of development of the earth's crust.

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HEXAGONAL PRISMATIC PARTING IN COALS⁷

by

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Hexagonal prismatic parting in coals is very rare, occurring as an exception. There are no known references to it in domestic literature. Yu. A. Zhemchuzhnikov noted [2, 3] that such parting has been observed in coked coals from some contact metamorphic zones of Germany, North America, and Mexico; in so doing he quoted the works of A. Uthemann and E. Moore [6, 7].

In 1892, A. Uthemann first described hexagonal parting of metamorphosed brown coals from the Meissner area, Germany, where Tertiary arenaceous argillaceous coal-bearing deposits are cut by basalt sills and dikes with columnar parting. The coals, usually brown, brittle, earthy, strongly moisture-absorbing acquire an anthracite aspect near the intrusive contact; their color changes to black (in places with a bluish hue); their density and hardness increase, and they take on a vitreous luster and a conchoidal to splintery fracture. Parting fissures are gradually developed, normal to the contact surface; first they are rare and indistinct, becoming more distinct and numerous as they approach the basalt.

In the vicinity of basalt, the coal is broken up into isolated hexagonal forms, resulting in the so-called "stick-coal" ("Stangenkohle"; A. Uthemann, [7]). These columnar formations, pentagonal to hexagonal in section, have a diameter of several milli-

meters to 3 centimeters. They are reminiscent of miniature columnar parting in basalt (Fig. 1).



FIGURE 1. "Stick-coal" at contact with basalt. Hirschberg mine (after A. Uthemann).

1 -- black coal; 2 -- stick coal; 3 -- basalt.

These "stick-coals" are dull to metallic in luster, like graphite; their fracture is finely conchoidal with an "augen" surface [7].

E. Moore reported in 1940 that natural coke with columnar parting occurs at contacts of coal beds with extrusive rocks in Colorado, Utah, Alaska, and in Mexico [6]. Judging from the accompanying photograph (Fig. 2), the coke parting is hexagonal and prismatic, i.e., similar to the "stick-coal" of A. Uthemann.

In his 1954 lithologic study of Lower Permian deposits on the Yurung-Tumus peninsula (northern Yakutiya), the author ran across a coal with hexagonal parting, also at the contact with basalt.

⁷O shestigrannoy prizmaticheskoy otdel'nosti v uglyakh.

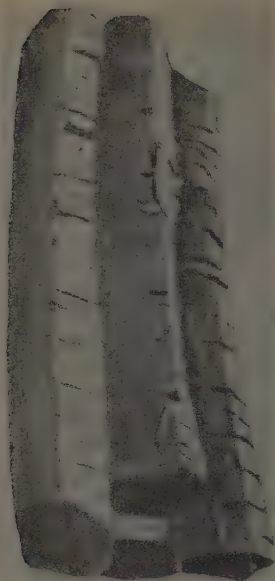


FIGURE 2. Columnar parting in natural coke (after E. Moore).

A coal bed, 0.9 meters thick, was penetrated by borehole P-42, at 1248 meters. It is associated with the lower part of the lower Permian Tustakh formation. This formation is made up of fine- to medium-grained sandstone and siltstone, interbedded with slaty shale, the whole sequence cut by sills and dikes of traprock.

A coal bed between sandstone and shale is in underground contact with a basalt sill, 2.5 meters thick (Fig. 3). The coal is dull, sooty, gray-black, with an uneven fracture, dense, leaving a black streak on a porcelain tablet. It exudes hydrogen-sulfide odor, when struck. The binocular microscope reveals a fine-grained surface with a well developed network of fine rounded pores, reminiscent of coke structure.

The hexagonal-columnar parting in coal is formed by the intersection of vertical fissures, to form a hexagonal pattern like that of a honeycomb (Fig. 4). The hexagonal form of the cells is commonly irregular, with the polygons flattened, in which case the prisms appear to be compressed on two sides; the angles are in places somewhat rounded, making the prisms look more like cylinders (Fig. 5).

The polygon sides range from 5 to 10 millimeters, with short sides in compressed forms cut down to 2 or 3 millimeters; the diameter of cylinder-like individuals is about 10 millimeters.

Fractures between individual prisms are filled with veins of transparent dolomite, 0.1 to 0.5 millimeters thick, as well as with calcite and quartz.

The vertical parting planes are normal to bedding and to the contact with basalt, and display a hatching, apparently determined by the stratification of coal (Fig. 5).

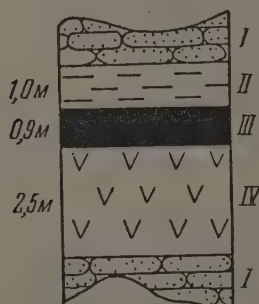


FIGURE 3. Cross-section of a coal bed with hexagonal columnar parting, on the Yurung-Tumus peninsula.

I -- sandstone; II -- shale; III -- basalt; IV -- coal.

NOTE: Comma represents decimal point.

A chemical analysis of this coal has shown a low moisture content ($W_a = 0.6\%$), a high ash content ($A_s = 31.9\%$), and a high degree of carbonization $C_g = 98.1\%$; $H_g = 1.1\%$, $N_g = 1\%$. The amount of volatiles (V_g) is 1.8% . X-ray analysis has established that the coal carbon is amorphous.

The coal ash contains silicon (5% of the total), calcium (3%), magnesium (2%), iron (1%), aluminum (1%), sodium (0.2%), manganese (0.02%), titanium (0.01%), chromium (0.003%), etc. Seen in reflected polarized light, the coal consists of a homogeneous groundmass with a considerable addition of mineral, evenly distributed inclusions. Fractures and pores are filled with calcite, dolomite, and quartz — secondary formations

having come probably from the intrusion.

In all of these examples, the hexagonal prismatic parting in coals is related to the presence of magmatic bodies (basalt), originally with a high temperature which has brought about a natural coking of coal.

The formation of this hexagonal parting in coals evidently is related in part to the contraction of coal beds in contact with igneous rocks. It is well known that profound structural changes take place in a bed of coking coal, at temperatures between 500° and 800°C, which lead to a 6 or 7% reduction in the volume of coal. In this process, especially with one-sided heating, a network of fractures develops in the coal; their intersections bring about a hexagonal prismatic parting (Fig. 6). In a thin coke bed, this network is fine, and so is the parting; in a thick bed, the fractures are

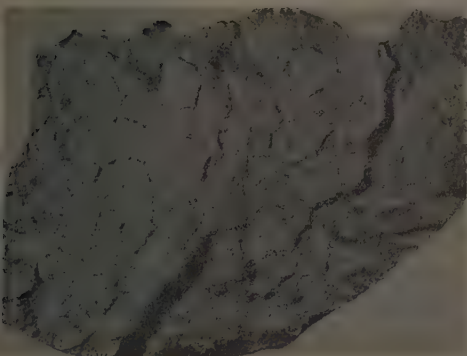


FIGURE 4. Columnar parting in coal from the Yurung-Tumus peninsula; plan view.

less numerous, resulting in larger prisms [5].

On the other hand, the formation of hexagonal parting is affected to a considerable extent by a volume decrease caused by the rapid loss of moisture and volatile components, as a result of the high temperature of intruded basalts [4]. The unaltered Meissner brown coals contain 30 to 50% moisture; its content drops 8 to 20% in black metamorphic coal and to 2 to 8% in "stick-coal" [7]. The moisture content in hexagonal prismatic coal from the Yurung-Tumus

peninsula was as low as 0.6%.

The content of volatile matter in the Meissner coals drops to 48% in normal brown coal and to 10 to 13% in "stick-coal" [7]. The volatile matter content in hexagonal prismatic coal from Yurung-Tumus is as low as 1.8%.

In coals with a low content of moisture and volatiles, hexagonal parting at contacts

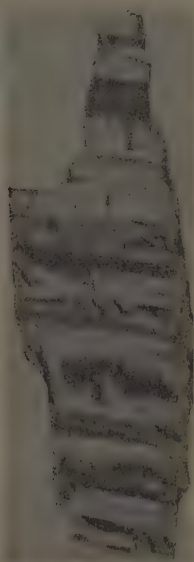


FIGURE 5. Hexagonal parting in coal from the Yurung-Tumus peninsula; longitudinal section.

with igneous rocks does not take place. For instance, Cretaceous coals from North Suchan, with 2 to 5% moisture and 12 to 16% volatiles, occurring in contact with andesite dikes and sheets (the Kazanka deposit) produce a powder-like coke rather than forming hexagonal parting.

Thus, the development of such parting in coals is a result of physical and chemical alterations in the coal, in zones of contact with igneous rocks, brought about by high temperatures. The appearance of this parting must be preceded by a complete

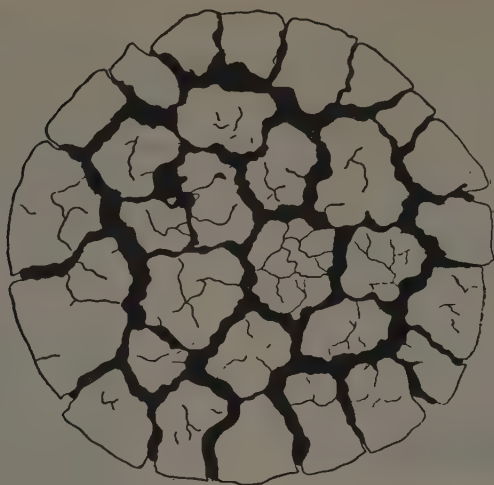


FIGURE 6. Parting in synthetic coke.
(After L.M. Sapozhnikov).

transformation of the wood remains in coal to an uninterrupted homogeneous mass. The loss of moisture and of volatiles from the latter brings about a shrinking which draws the substance toward definite centers and produces a polygonal pattern of fracturing [1].

In this country, hexagonal prismatic parting was not known until recently. Of interest in this connection are Tertiary coals from Sakhalin. Here, in the Brodyazhka coal field, A.M. Tsvetkov described, as early as 1931, "characteristic prismatic parting" in coals at contact with basalt dikes. The unaltered coals carry up to 8% moisture and up to 35 or 45% volatiles. That parting probably is similar to the one we have described.

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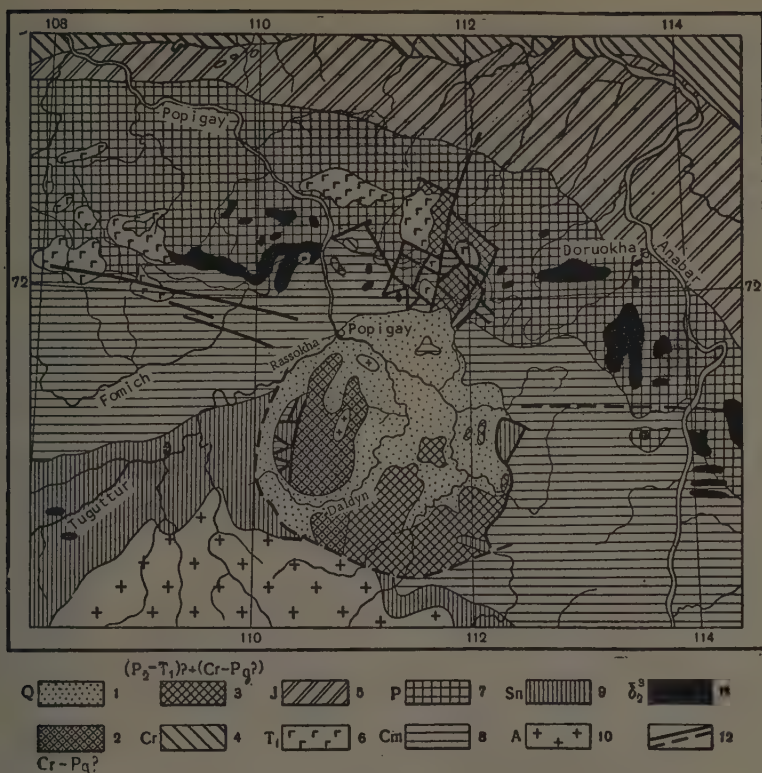
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FROM THE EDITORIAL BOARD

A paper of M.T. Kiryushina, *Manifestation of Mesozoic and Cenozoic Volcanism on the Northern Edge of the Siberian Platform* was published in No. 1, 1959.



Generalized Map of the Popigay Depression

1 -- Quaternary deposits; 2 -- Mesozoic and Cenozoic tuff and tuffaceous lava of an intermediate composition; 3 -- undifferentiated basic Permian or Triassic (?) and Mesozoic and Cenozoic tuff and intermediate tuffaceous lava; 4 -- Cretaceous deposits; 5 -- Jurassic deposits; 6 -- Lower Triassic lava formation; 7 -- Permian deposits; 8 -- Cambrian deposits; 9 -- Sinian deposits; 10 -- Archaean; 11 -- Upper Paleozoic - Lower Triassic traprocks (dolerites, gabbroic diabase); 12 -- actually traced and identified (solid line) and assumed (dashed line) major faults.

The manuscript was accompanied by a generalized geologic map of the Popigay depression, with an area of about 60,000 square kilometers, reaching as far as the coast of the Arctic Ocean.

The paper, which deals with the manifestations of Mesozoic and Cenozoic volcanism, does not go into the general geologic struc-

ture of the northern rim of the Siberian platform. Without consulting the author, the editorial staff printed only a geographic map enclosed by M. T. Kiryushina.

Published here is the south half of a geologic map for the Popigay depression, with evidence of volcanism mentioned in the M. T. Kiryushina paper.

GRIGORIY NIKOLAYEVICH KAMENSKIY (OBITUARY)¹

Soviet hydrogeologists have suffered a heavy loss with the death, on July 17, 1959, of Professor Grigoriy Nikolayevich Kamenskiy, an outstanding hydrogeologist, a gifted educator, and Corresponding Member of the Academy of Sciences, U.S.S.R.

G.N. Kamenskiy was born in the village of Klekotki, the Yepifanovskiy Uyezd (district), Tul'skaya Guberniya (Province), on January 19, 1892. After graduating from the village school, he passed the "maturity certificate" examination, as a "free lance" in 1910, and entered the Moscow Agricultural Institute (now the Timiryazev Agricultural Academy). In 1916, he graduated from the ameliorative engineering department of that institution and was invited to stay on, in preparation for teaching. Even as a student, G.M. Kamenskiy worked — in partial fulfillment of his program — in the former Department of Land Improvement, Ministry of Agriculture, as a technician and hydrogeologist, and even then he proved to be a thoughtful research worker. After graduation, along with his research, he worked in the Commission for phosphate study in the Volga and Don regions.

From the first days of the Great October Socialist Revolution, he took up hydrogeologic study in the Moscow and Penza Provinces, and in 1920 he began to teach hydrogeology in the Timiryazev Agricultural Academy and the Moscow Mining Academy, where the first formal course of hydrogeology was established at that time for the training of highly qualified hydrogeologists.

While in the Mining Academy, G.N. Kamenskiy carried on an extensive work of organizing hydrologic laboratories, of setting up a curriculum and methods of study, of introducing new disciplines, and on compilation of textbooks.

Beginning with 1930, when the Geological Exploration department of the Academy was

reorganized as the Moscow Geological Exploration Institute, G.N. Kamenskiy became chairman of the Hydrogeology Department, in which position he remained until 1955.

Along with his teaching and research work in the Geological Exploration Institute, he carried on, at various periods, scientific work for a number of organizations, such as the Amelioration Section of the Narkozem (People's Commissariat of Land); the Moscow Geological Exploration Administration; the All-Union Scientific Research Institute of Water Supply, Canalization, Hydrotechnical Construction, and Engineering Geology; the All-Union Scientific Research Institute of Hydrogeology and Engineering Geology; and the Institute of Geologic Sciences, Academy of Sciences, U.S.S.R.

From 1951 to the end of his days, he worked in the Laboratory of Hydrogeologic Problems, Academy of Sciences, U.S.S.R., of which he was director, for some time.

The service of G.N. Kamenskiy in the field of development of a Soviet school of hydrogeologists was immense: he was one of its organizers and a leading scientist. He was a scientist of vision in the field of geology and hydrogeology. The scope of his scientific interests embraced regional geology and hydrogeology; the dynamics, the status, and the formation of ground water, engineering geology, and methods of hydrogeologic study. This diversity of interest has found its reflection in his publications.

The early works of G.N. Kamenskiy dealt chiefly with regional geology and the hydrogeology of the Middle Don basin, Penza Province, and the Manych area, Yergeni Plateau, Obshchiy Syrt, and the Caspian trough. Outstanding among them are his new interpretation of the geologic structure of the Donets Dome and a description of the Don-Donets artesian basin; his discovery of salt tectonics in the south of Obshchiy Syrt, and of hitherto unsuspected stratigraphic units (Oxfordian-Kimeridgian, Santonian, Danian), and of oil

¹ Grigoriy Nikolayevich Kamenskiy.

shale. Data of G.N. Kamenskiy was the basis for drilling of a deep borehole, as a result of which a potassium deposit was discovered in the Obshchiy Syrt area.

The results of regional work were used by G.N. Kamenskiy in his formulation of the principles of hydrogeologic differentiation and of scientific foundations for the method of hydrogeologic study and prospecting, published in a number of papers and school manuals, particularly in his widely-known book, Search and Exploration for Ground Waters.

The work of G.N. Kamenskiy in the dynamics and status of ground water was inspired by practical needs in connection with the construction of major hydrotechnical projects. For example, as early as 1930 to 1935, he carried out a number of research projects on the scientific method of determination of ground water pressure, of the study of rock filtration properties, and the determination of the ground water resources.

He consulted and actively participated in the construction of the Volga-Don canal, the Moscow Canal, the Stalingrad Hydroelectric Station, the Moscow subway, as well as the Kolkhistroy, the Kuybyshev Hydroelectric Center, the Mingechaur Hydroelectric Station, and irrigation systems in the Kura-Araks Plain, the Caucasian Mineral Waters, and in the development of North-Uralian bauxite deposits.

G.N. Kamenskiy performed a true scientific feat by turning the descriptive science of ground water into a science capable of giving qualitative solutions to problems of the nation's economy. He has created one of the most important divisions of hydrogeology: a theory of the dynamics and status of ground waters, which is his lasting contribution to science. Of special interest is his work on the movement of ground water in heterogeneous formations, on the hydrodynamic basis of forecasting the status of ground water, an original method of solving the problems of their unstabilized movement, and on forecasting their status by the terminal differences method. His text, Principles of the Dynamics of Ground Water, had two printings; at his recommendation this subject was introduced into the curriculum of hydrogeologic departments in geologic exploration institutes.

G.N. Kamenskiy greatly contributed to the creation and development of the study subject, "Ground Water of the U.S.S.R." He lectured on that subject for 20 years; in his last years, he wrote a text on it.

In addition, G.N. Kamenskiy is the author of many other works, a total of over one hundred titles. His major scientific works are hydrogeologists' handbooks which have been translated into the languages of many people's democracies.

The high level of his scientific achievements earned him Corresponding Membership in the Academy of Sciences, U.S.S.R.

His scientific work in the Laboratory of Hydrogeologic Problems was very fruitful; he kept it up to the end, although he was very ill for his last few years.

He also was in charge of the extensive work of the Academy of Sciences in the development of a major task of the Academy: a broadening of international cooperation in the field of hydrogeology and engineering geology. He was Vice President of the International Association of Hydrogeologists and Chairman of the Soviet Hydrogeological Section of the National Committee of Geologists of the U.S.S.R.

He also was member of the academic councils in many institutions and scientific societies, was socially active as a deputy of the Moscow Municipal Soviet, of the First Session, and deputy of the Krasnopresnenskiy District Soviet, Third Session. For his scientific and industrial achievements, he was awarded orders and medals of the U.S.S.R.

G.N. Kamenskiy was a man of integrity, unassuming, and charming. He was a highly cultured man, a great lover of music, and a good fellow worker and friend.

The memory of Grigoriy Nikolayevich Kamenskiy — a talented scientist and an excellent man — will always live in the hearts of those who knew him.

I. V. Garmonov,
F. A. Makarenko,
A. M. Ovchinnikov

LOSSES TO SCIENCE

Corresponding member of the Academy of Sciences, U.S.S.R., Nikolay Nikolayevich Slavyanov passed away on October 16, 1958. He was the oldest Soviet hydrogeologist. For the data of his life and scientific work, see an article by D.I. Gordeyev, T.P. Afanas'yev, and F.A. Makarenko, "To the Memory of Nikolay Nikolayevich Slavyanov," in this journal, No. 6, 1959.

On October 28, 1958, Vasilii Petrovich Novikov died; he was for many years a member of the State Commission on Mineral Reserves at the Council of Ministers of the U.S.S.R., and a member of the Communist Party of the Soviet Union. He was born March 8 (February 25) 1884; from 1900 on, he worked in various Moscow factories, was active in the revolutionary movement of 1904 and joined the Russian Socialist Democratic Workers' Party (Bolshevik faction). He held responsible positions after the Great October Socialist Revolution, including acting directorship of the Geological Committee and acting directorship of the Main Geological Exploration Administration of the All-Union Soviet of the People's Economy (VSNKh) of the U.S.S.R.

In 1935, he graduated, as "free-lance" (extern) from the Moscow Geological Exploration Institute and was appointed acting chairman of the Central (subsequently All-Union) Commission on Mineral Reserves where he remained until his death.

For his fruitful organizational activity in the development of general principles of evaluation of mineral deposits and of determining and estimating mineral reserves, he was awarded the Order of Lenin, two orders of the Toilers' Red Banner, the Order of Merit, and other medals.

Ibragim Nagi Ogly Aslanov, Candidate of Geological and Mineralogical Sciences and Senior Scientist of the Geological Institute, Academy of Sciences, Azerb. SSR, passed

away on November 23, 1958. He was born December 24, 1908 and graduated from the Geological Exploration Institute of the Academy of Sciences, Azerb. SSR. In 1926, he worked first as a technician, then as laboratory assistant in the Geological Exploration Administration and the Azneft' Scientific Research Institute. Afterwards he studied copper ore deposits in the Little Caucasus and worked on paleontology and stratigraphy of lower Oligocene deposits in the northeastern foothills of the Little Caucasus.

On February 13, 1958, Viktor Aleksandrovich Priklopskiy passed away. He was Corresponding Member of the Academy of Sciences, U.S.S.R., Director of the Laboratory of Hydrogeological Problems at the Academy, and Professor of the Moscow Geological Exploration Institute, and one of the outstanding Soviet experts in the field of hydrogeology and engineering geology. For his obituary see *Izvestiya*, No. 9, 1959.

On March 1, 1959 Aleksandr Vasil'yevich Shcherbakov died. He was Candidate of Geological and Mineralogical Sciences, Senior Scientist of the Scientific Research Institute of Arctic Geology, and member of the CPSU. He was born on March 1 (February 16), 1903 and graduated from the mining department of the Far Eastern State University in 1930.

His main work was on the geology of Sakhalin, Kamchatka, and the extreme northern U.S.S.R. Of great interest is his work on the geology of the Taymyr fold zone in the Koryak Range and on oil and gas of the Ust'-Yenisey region.

A.V. Shcherbakov was awarded the Order of the Toilers' Red Banner and other medals.

On March 24, 1959, Doctor of Geological and Mineralogical Sciences, Professor Leonid Yakovlevich Nesterov passed away. He was in charge of the course of study of mining geophysics in the Leningrad Mining Institute, and a former director of VSEGEI. His obituary is printed in *Sovetskaya Geologiya*,

¹ Poteri nauki.

LOSSES TO SCIENCE

No. 8, 1959.

Stepan Il'ich Mironov passed away on March 30, 1959. He was the oldest Soviet petroleum geologist, in charge of the Laboratory of the Origin of Oil, Institute of Geology and Production of Mineral Fuels at the Academy of Sciences, U.S.S.R. For his obituary see *Izvestiya*, No. 7, 1959.

Associate Professor, Candidate of Geological and Mineralogical Sciences, Mikhail Stepanovich Baklakov died on April 22, 1959. He was a member of CPSU. He was born on January 22, 1905, graduated from the Geological Department of Tomsk State University (1930) and worked in western Siberia.

Having defended his candidate's thesis in 1948, he went to the North Caucasian Institute of Mining and Metallurgy where he was first in charge of the course of study of minerals and mineral exploration, then Dean of the Mining and Metallurgical Department and Acting Director of the Institute.

Most interesting among the published works of M.S. Baklakov are his papers on geology and metallogeny of the Central Caucasus. Shortly before his death, he completed a monograph on metallogeny of the northern Caucasus.

M.S. Baklakov was awarded the Order of Merit.

Matvey Alkunovich Kapelyushnikov passed away on July 5, 1959. He was a prominent Soviet oil man, Corresponding Member of the Academy of Sciences, U.S.S.R., Superintendent of the Laboratory of the Institute of Geology and Production of Mineral Fuel at the Academy of Sciences, U.S.S.R., and a recognized leader in the field of science and technology of the U.S.S.R.

He was born of September 13 (1), 1886, graduated from the Tomsk Technological Institute (1914), and worked for a long time in the Baku oil industry. Here, he had a number of responsible positions in industrial and scientific research organizations and was awarded the rank of Hero Of Labor of the Azerb. SSR.

Beginning with 1937, M.A. Kaleryushnikov worked in Moscow, in the system of Academy of Sciences, U.S.S.R. and as Professor at the Moscow Petroleum Institute. He wrote about many discoveries and inventions, such as turbodrilling, the first Soviet cracking plant, pneumatic remote control of wells, etc. Of great importance in the development of petroleum geology was the discovery in 1952 of the phenomenon of oil solution dissolved in gas under pressure. On the basis

of this fact, M.A. Kapelyushnikov proposed a hypothesis successfully explaining many hitherto obscure features of the migration and accumulation of oil.

He was awarded two Orders of Lenin; the Order of Patriotic War, First Class; three Orders of the Toilers' Red Banner, and other medals.

Corresponding Member of the Academy of Sciences, U.S.S.R., Grigoriy Nikolayevich Kamenskiy passed away on July 17, 1959. He was one of the outstanding Soviet hydrogeologists, an expert in the dynamics and status of ground water. His obituary is printed above.

Teodor Maksovich Dembo died on July 20, 1959. He was Doctor of Geological and Mineralogical Sciences and Senior Scientist at the All-Union Institute of Scientific and Technical Information, Academy of Sciences, U.S.S.R. He was born on December 25 (12), 1910, graduated from the Geology Department of the Leningrad Mining Institute in 1934, and worked on various geologic expeditions and organizations: as Senior Scientist for the NIGRI Gold, then in the Scientific Research Section of the Ordzhonikidze Moscow Geological Exploration Institute. He defended his Candidate's thesis in 1941 and received his Doctor's degree in geologic and mineral sciences. Of considerable interest are his works on contact metamorphism in the Kalaminsk intrusion, in the north Yenisey taiga, and especially in lower Paleozoic stratigraphy, tectonics, and igneous activity in north of the Kuznetsk Alatau.

T.M. Dembo has translated into Russian, G. Reed's *Meditations on Granites*, Huan Bo-Tsin's *Main Tectonic Features of China*, and M.S. Krishnan's *Geology of India and Burma*.

Nikolay Ivanovich Vlodavets passed away on July 31, 1959. He was Candidate of Geological and Mineralogical Sciences and a prominent expert in the field of chemical study of mineral resources. He was born on June 13 (1), 1890. In 1918 he graduated from the Department of Metallurgy, Leningrad Polytechnic Institute, and worked all his life in the Academy of Sciences system: first in the Section of Non-Ore Minerals of the Commission for the Study of Natural Productive Forces, then in the Institute of Geological Sciences and the Laboratory of Mineralogy and Geochemistry of Rare Elements, from which he was pensioned in 1954.

N.I. Vlodavets worked under the direction of A. Ye. Fersman in Khibiny and on the study of minerals in Emerald Mines, the Urals, and sulfur deposits in the Kara-Kum Desert.

Of considerable interest are his works on

geochemistry of rare elements — gallium, indium, and thallium. In his application of geochemistry to technology, he carried out extensive experimental work in the decomposition of nepheline. His method of obtaining metallic aluminum was eminently successful in assimilating the natural resources of Kola Peninsula. For that work, he was awarded the 1957 Lenin Prize.

N.I. Vlodavets was also awarded the Order Of Lenin and other medals.

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V.V. Tikhomirov and L.B. Bel'skaya

REVIEWS AND DISCUSSIONS

ON THE NATURE OF ULTRABASIC BRECCIA IN THE KRAK MASSIF, SOUTH URALS¹

by

S. V. Moskaleva

A paper of G. M. Gapeyeva and N. P. Verbitskaya on eruptive ultrabasic breccia in the Krak massif, South Urals was published in Doklady of the Academy of Sciences, U. S. S. R. (122, No. 2, 1958).

The formation in question, which we shall call "breccia," was discovered by this author in the summer of 1956, during a study of the Krak peridotite massif. Because of the poor exposure, the observations were of such a general nature as to preclude any definite conclusion on the genesis of this peculiar formation; a publication of some speculative conclusions appeared to be premature.

In 1957, the Krak massif was visited by one of the authors of the paper under review, G. M. Gapeyeva, with the specific purpose of studying the alleged eruptive breccia from artificial exposures. In the subsequent 1958 study of this massif, we found evidence of diggings, somewhat enlarging the outcrop area without, however, uncovering any geologic relationship. For that reason, the supplementary study was but a refinement of the preceding one.

Thus, repeated study has failed to reveal the nature of this breccia, with adequate certainty. However, because of the appearance of the paper presently under review, with many errors which may lead to many theoretical and practical misunderstandings, I am compelled to make the following statements:

1. The breccia is located not in the South Krak, as stated on numerous occasions in the paper, but in the northern part of the North Krak, in the channel of a right tributary of Sukhoy Uzyan River, 500 meters above its confluence with the left tributary.

2. Interest in this formation was a result of our study described in two manuscripts. The very visit of G. M. Gapeyeva was based on our preliminary data, in direct contradiction to the authors' statement that the finding of the breccia "was not given proper consideration" (p. 281).

3. The same page 281 carries a reference to an exposure of direct contact of breccia and ultrabasics, in the Sukhoy Uzyan channel. Farther on, turning back to the contact, after a description of the "breccia" itself, the authors state, "The breccia forms intrusions in the ultrabasic massif, entering it through fractures which wedge out 0.5 to 0.75 meters from the contact" (p. 282). As a matter of fact, the river channel is represented by solid breccia, with its contact with the ultrabasics not yet exposed. Inasmuch as a most careful search, in 1958, failed to uncover any trace of contacts in ditches walked-out by G. M. Gapeyeva in 1957, we leave the existence of these "intrusions" entirely to the responsibility of the two authors. Thus the lack of exposed breccia-peridotite contacts remains the main obstacle to a solution of the genesis of that formation.

4. Also erroneous is the authors' reference to the presence of grinding in ultrabasics at the breccia contact, which they believe to be related to the origin of the breccia, "because ultrabasics at the immediate contact are often shattered and turned to serpentized and carbonatized tectonite" (p. 282; italics mine - S. M.). What really takes place is that ultrabasics in the left bank of Sukhoy Uzyan - whose channel exposes the breccia outcrops - is cut by zones of intensive fracturing and shattering, with thin veins of pseudotachylytes. These zones are shaped like rectilinear bands

¹O prirode giperbazitovoy brekchii massiva kraka na Yuzhnom Urale.

oriented S 10 to 30° E, i.e., across the trachytoid trend of ultrabasics, which is here, as elsewhere in the massif, N 60 to 80° W.

These fractures and shattered zones and the appearance of pseudotachylytes are not peculiar to this area. They are a typical feature of the Krak massif where zones of shattering and intensive shearing and the trend of pseudotachylytes are everywhere oriented nearly meridionally, trending northeast and perpendicular to the equally definite northwesterly, almost latitudinal trachytoid trend of ultrabasics and other elements of primary structure of the Krak massif.

What is more, thin pseudotachylyte veinlets, running across the usual trend, are readily seen under the microscope, as evidence of cataclastic phenomena, in both the ultrabasic fragments in breccia and in the ultrabasics themselves, everywhere in the massif. It is quite obvious, therefore, that the presence of fault zones is typical of the entire Krak massif rather than of the breccia area, and that their formation is not related to breccia but occurred prior to it. In this connection, it is of interest that ultrabasics on the right bank of Sukhoy Uzyan, nearer to the breccia outcrops than those of the right bank, are quite intact and do not show any trace of shattering.

No carbonatization has been observed in ultrabasics at their contact with the breccia, and their serpentinization is in no way different from the usual.

5. While assuming that the breccia is eruptive and younger than the enclosing ultrabasics, the authors state nevertheless, on the subject of shearing in its cement, that "the latter (i.e., the schistosity - S.M.) evidently is related to the proximity of the contact with ultrabasics which enclose the breccia, because they are shattered and turned to tectonite, at the immediate contact" (p. 282). Even without any proof, the utter improbability of a dynamic effect of older formations on the younger ones which cut them, with the development of rectilinear shear planes in the younger formations, is obvious.

6. With regard to the petrologic composition of rocks making up the breccia fragments, the authors note among them "fragments of picrite porphyrite and tuff, and occasional fragments of jasper-like siliceous shale" (p. 282). They do not substantiate this statement by a petrographic description; it appears that their assertion is based on an arbitrary interpretation of our material. As a matter of fact, a closer and more detailed observation reveals that "picrite porphyrite" and "tuff" are fragments of hartzburgite and

lehtzolite from the pseudotachylyte zone, while the jasper-like "siliceous shales" are fragments of siliceous serpentine, common in peripheral parts of the Krak massif.

7. The description of breccia cement is also incorrect. It is represented not by "a serpentine-carbonate mass with an addition of pelitic material and hydromicas" (p. 282) but exclusively by carbonate having in part a serpentine-chlorite and olivine-pyroxene composition, representing relicts of peridotite fragments replaced by carbonate. Mistaken for pelitic material were iron oxides common in serpentine rocks.

8. In concluding their study, the authors left open the question of the nature of this formation. In the very next paragraph, however, taking this uncertainty for their premise, they came out with a new and curious idea of the geologic structure of the Urals, which indeed exposes the obvious slant of the entire article.

Along with these errors and inaccuracies, the article naturally lacks much data which we have at our disposal. Staying close to actual observations supplemented by the 1958 study, the following statement is warranted for the Krak massif breccia.

This breccia is located in the peripheral part of the massif, among ultrabasics, 100 meters east of their contact with the Bertinsk schist. It is oval in plan, somewhat elongated nearly meridionally; its visible dimensions are 160 x 70 meters. The breccia has a limited distribution, occurring in the floor of an amphitheater whose nearly sheer walls are made up of ultrabasics of the hartzburgite series. The latter exhibit a distinct trachytoid structure trending N 60 to 75° W. Normal to it are rectilinear zones of shattering common to the Krak massif, having the appearance of pseudotachylytes; the thickness of these zones ranges from fractions of a millimeter to 25 centimeters.

The breccia rock is not uniform, being represented by a fine-grained light grayish-yellow carbonate cement with angular to rounded fragments of peridotite, dunite, and serpentinite, from a fraction of one millimeter to 0.5 meters in diameter. Some cement segments, particularly those poor in ultrabasic fragments, are porous, possibly due to leaching of carbonate. The orientation of the fragments and their density in the breccia are different as are their dimension and form. Most fragments are smooth, as if rounded, although their rocks are quite fresh, without any evidence of weathering or other alteration common in typical alluvial deposits of other streams in the Krak massif. The breccia cement is finely and nearly

horizontally laminated, with the laminae striking N 5 to 10° E and dipping northwest at 10 to 20°.

A microscopic study has shown that the breccia fragments are represented exclusively by ultrabasic rocks of the Krak massif, and by mineral components of these rocks. A vast majority of fragments are hartzburgite close to dunite in composition, and by serpentine. Less common are lehtzolit, dunite, and feldspathic peridotite. About the same quantitative relationship exists in the Krak massif ultrabasics.

The hartzburgite rocks consist of variable amounts of olivine and rhombic pyroxene. Their accessories include monoclinic pyroxene, chromite, magnetite, and zircon. Secondary minerals are represented by serpentine.

Olivine, which makes up the bulk of rock, belongs to forsterite with about 1% of a fayalite component ($\gamma' = 1.667$ to 1.668 ; $\alpha = 1.632$). It forms coarse grains, slightly elongated, which determines the general texture. The degree of its serpentinization varies from low to total.

Rhombic pyroxene is subordinate, not exceeding 2 or 3%. Its optic constants ($\gamma' = 1.656$; $\alpha' = 1.650$) suggest its association with enstatite proper.

Monoclinic pyroxene is represented by emerald-green grains of chrome-diopside ($c \gamma = 37-38^\circ$; $\gamma' = 1.698$; $\alpha' = 1.672$). Present in thin section, in addition to these minerals, are chromite and magnetite; the grit of these rocks also contains garnet and zircon with a refractive index between 1.754 and 1.746. Pyrope is the dominant garnet component. The structure of these rocks is typical of the Krak massif hartzburgites. The rocks consist of coarse grains of olivine and enstatite. As in similar Krak massif rocks, olivine forms numerous poikilitic formations in the enstatite, both along the cleavage planes and at an angle to them. Such a relationship suggests a later formation time for the olivine in these rocks.

The fragment rocks, like the Krak massif ultrabasics, are marked by their elongated structures determined by the parallel orientation of grains of olivine, and less commonly of enstatite. Like the Krak massif ultrabasics, the fragment rocks always carry evidence of cataclastic phenomena, such as the wavy extinction of olivine and the bending and fracturing of pyroxene grains. Such phenomena are best expressed in pseudotachylytes, present both in isolated thin zones and in networks of fine "veinlets". As in the massif's ultrabasics, such zones are oriented normal to the structure of the rocks.

Not uncommon in the fragments are serpentinites among which are present all of the serpentine varieties of the Krak massif, including siliceous serpentine.

A comparison of all these features points to complete identity of the fragment rocks with those in the massif.

A mineralogic study of thin sections of the breccia has revealed the presence of monoclinic pyroxene (chrome-diopside, diopside), rhombic pyroxene, olivine, chromite, and chrome-picotite. The same composition is typical of thin sections of rocks from the Sukhoy Uzyan channel, both above and below the breccia site. A mineralogic study of breccia grits has revealed the presence of the same minerals with rare showings of zircon, a pyrope-type garnet, almandite and calcite.

Under the microscope, many thin sections of the breccia cement show organic remains. Recognizable among them are two types - rounded and lenticular cross-sections with a concentric nuclear structure, and reticulate cross-sections, commonly torn apart. According to the VSEGEI (All-Union Geological Institute) paleobotanists (V. G. Lepekhina), these forms are peculiar to a steppe flora at the close of the Paleozoic and the beginning of the Mesozoic.

The breccia cement is represented chiefly by carbonate, with occasional small pockets of chlorite and serpentine. The carbonate is essentially calcite with a small addition of siderite. The cement usually is a fine-grained aggregate of elongated prismatic grains; the latter are in places zoned and rounded. The floral remains are associated usually with such segments.

The relationship of cement and the fragments deserves some attention. The cement not only separates and holds together the fragments; in a number of places, carbonate veins, shooting out of more or less massive bodies of cement, penetrate the cracks in fragments, gradually replacing them. As a result, olivine-pyroxene, serpentine, and chlorite spots are left in the carbonate body, creating the illusion of a primary ultrabasic cement in the rock, while they are in fact the remnants of ultrabasic fragments replaced by carbonate.

Thus, data on hand can be summed up as follows:

1. The breccia has a limited distribution and appears to form a compact body.
2. The breccia fragments are represented exclusively by ultrabasics whose complete

similarity with the rocks of the massif in mineralogical and structural features, is unquestionable. No other rocks have been observed in the breccia.

3. A special study has revealed the presence of a pyrope-type garnet which is a typomorphic kimberlite mineral.

4. The floral remains suggest that the breccia surface was in a weathering and soil-making zone, at the end of the Paleozoic and the beginning of the Mesozoic.

Thus, material on hand is not critical and may indicate either an eruptive or an alluvial origin of this formation. The presence in the breccia of numerous rounded fragments, represented moreover only by ultrabasics of the Krak massif, along with the absence of any but those minerals present in the surrounding rocks and the absence of any special dynamic disturbances and alteration in the surrounding ultrabasics — all seems to be in favor of a possible alluvial origin of this breccia. These facts, however, do not preclude some other origin for it. The presence of rounded fragments is also known in kimberlite, while the presence of only ultrabasic rock and mineral fragments can be fully explained by the composition of the intruding rocks.

Indeed, the local distribution of the breccia, its strictly limited area, the absence of similar formations among alluvial deposits elsewhere in the massif, the presence of such specific typomorphic kimberlite minerals as pyrope, zircon, and chrome-diopside — all this permits a non-alluvial origin for the breccia. One of the conspicuous factors is the presence of the amphitheater with sheer walls, in the surrounding ultrabasics, with the breccia at its floor.

The above exposition goes to show that material on hand is inadequate for a final determination of the nature of the breccia in question. A solution to this problem is possible only after a determination of the nature of the contacts of this body and of its depth and form. That will be achieved only by substantial mining work.

"LOWER RHINE BROWN COAL FORMATION,"² A REVIEW³

by

V. S. Yablokov and L. I. Bogolyubova

The book, Lower Rhine Brown Coal Formation, was published in 1958 by the State

Geological Survey of North Westphalia-Lower Rhine, Federal German Republic; R. Teichmüller and G. Brelie, Editors; it contains 750 pages with many graphs, paleontological tables, etc. This is a collection of papers in various fields of geology of the Lower Rhine brown coal formation, by 56 authors.

The book consists of two parts: 1) Oligocene deposits of the North Sea and Lower Rhine Bay; and 2) continental Oligocene and Miocene deposits in the south of Lower Rhine Bay. Both parts are subdivided in sections. We cannot give even a brief outline of each paper and we confine ourselves to a description of the sections with references to a few authors.

Part One has three sections. Section One describes the lithology of rocks (from boreholes) in various stratigraphic subdivisions penetrated in the area (Upper Carboniferous, Upper Cretaceous, Paleocene, Oligocene, Miocene, Pliocene, and Pleistocene). New data are cited on lower beds of the Lower Rhine brown coal formation.

Section Two describes the methods of study of the grain size of the terrigenous rocks and gives descriptions of marine deposits in the area of Lower Rhine Bay. The course of Upper Oligocene sedimentation is traced by the change in grain size.

A paper of F. Berger cites interesting data on erosion and on sand "intrusions" in coal beds of Frimmersdorf and Morken. It is noted that sand deposited in the Frimmersdorf sequence contains fragments of brachiopods and foraminifera and is therefore marine.

The intrusion of sand into the underlying Morken sequence is considered in connection with erosion of the overlying Frimmersdorf coal bed and the squeezing of sand out of soil. Another author, M. Bajor, regards similar intrusions in the same bed as the result of tectonic movements contemporaneous with sedimentation.

It should be noted that the explanations by both authors are not sufficiently clear and convincing. Such phenomena are fairly common in coal beds of other basins, as well, and require careful study.

Band 1 und 2. Redaktion: R. Teichmüller und G. Brelie. Fortschr. Geol. Rheil. u. Westf. Herausgegeben von Geolog. Landesamt Nordrhein-Westfalen. Krefeld, 1958.

³O knige "Nizhnereynskaya Burougol'naya format-siya".

²Die Niederrheinische Braunkohlenformation.

There are a number of papers on the enclosing rocks, the inter-coal units and their lateral changes, and on other inclusions in the Frimmersdorf, Hartzbayer, and Morken. There are data on uranium accumulation in marine deposits. An interesting phenomenon is described, i.e., the filling up of a fracture up to 50 centimeters wide in sand of the Morken bed, by humus gel. According to F. Berger, this is due to penetration of colloid humus solutions from a coal bed.

Section Three deals with the Tertiary fauna in marine deposits and with stratigraphic problems. Various species of spores and pollen are described, along with their association with definite subdivisions of the Tertiary (Paleocene, Miocene, Middle Miocene). Various faunas are described (ostracods, foraminifera, corals, pectinids, fish remains, etc.), with their stratigraphic significance; the ecology and facies associations are determined for a number of cases.

Part Two consists of five sections.

Given in Section One are geophysical data and some paleogeographic conclusions arrived at in the study of distribution of spore assemblages throughout the south Lower Rhine Bay, during the Cretaceous and Tertiary.

Section Two sheds light on tectonic and stratigraphic problems of continental Eocene deposits. There is a brief description of rocks (quartz sand, clay, etc.) along with material on the age and distribution of coal beds in the Kladbach area and a description of thin-bedded coals (Blatterkohle). A paper of E. Schroder and M. Teichmüller cites data on dolomite-filled fractures in sandstone and explains their origin.

Section Three deals with the source material and the structure and facies of peat accumulation in the Main coal bed, from the Lieblar and Grulwerk shafts, G. Neuy-Stolz notes that the Main horizon is made up of alternating "light" and "dark" layers, 10 to 40 centimeters thick, and of a few thin intercalations of argillaceous rocks.

The source material of coal in the bed was represented by remains of assorted plants found in the coal: stems, trunks, tissue, spores, cuticle, pitch bodies, and remains of mushrooms involved in the decomposition of the original material.

A paper of M. Teichmüller and R. Tomson gives microscopic, macroscopic, and chemical descriptions of peat facies: marshes with a coniferous forest, marshes with angiosperm plants, reed marshes, and lacustrine deposits.

A characteristic feature of coals formed in marshes with conifers and angiosperms is the presence of a considerable amount of well-preserved fragments of stems and trunks, and a low spore and pollen content. The reed marsh coals are marked by the strong decomposition of their plant material and by a higher content of spores, pollen and mushroom remains. Lacustrine deposits are represented by cannel coal and by a comparatively high clay content.

From chemical data, reed marsh coals, unlike forest coals, contain more hydrogen, bitumens, cellulose, humic acids, and have a low pH. The lacustrine coals, unlike the forest and reed marsh coals, are marked by their higher ash content, a considerable amount of bitumens and nitrogen, and a lower content of cellulose and humic acids.

It is pointed out that "light-colored coals" belong to the reed marsh facies, while "dark" coals belong to the forest marsh facies. However, G. Neuy-Stolz associates the origin of light-colored coals not with the change in vegetation but with the allochthonous origin of these coals.

It should be noted that, according to our observations, thick Tertiary coal beds of Baskiria and the Ukraine also are differentiated into dark and light; however, we are unable to explain such differentiation either by the difference in source material or by the method of its accumulation (allochthonous). It is possible that the basic reason for such a difference lies in the chemistry of the sedimentary environment.

In another paper, M. Teichmüller presents a reconstruction of various types of marshes where the Main coal horizon has been formed. He does this on the basis of a paleobotanical analysis and a comparison with present subtropical coastal marshes. The paper is well illustrated by color reproductions of various types of marshes.

Papers by other authors cite data on faulting and folding of the Main coal unit. Recognition is given to the relations of bracketing properties of coals to the facies composition and to chemical and technologic indexes of a coal bed.

Section Four gives a lithologic description of beds overlying the Main coal unit and treats tectonic problems in the area of its distribution. It also cites data on the degree of oxidation of coals from this unit and the main criteria for its determination.

Section Five, and the last, is a summary of the whole book. This is a large article by R. Teichmüller, presenting general

conclusions on stratigraphy, tectonics, paleogeography, and climate, as well as problems requiring further study. R. Teichmüller bases his conclusions on the work of many authors, in various fields of geology and on the methods of study of the Lower Rhine brown coal formation, as well as his own observations.

Data on the stratigraphic differentiation of the Lower Rhine brown coal formation are compiled in a detailed table. It shows that this formation is represented by continental deposits in the south Lower Rhine Bay, and marine in the north, and that it belongs to various subdivisions of the Oligocene and Miocene. The formation of the Main coal unit took place in the Helvetian and Tortonian. The Pleistocene, as it appears from the text, is not distinguished by any sizable development of coals, and deposits of that time are regarded as an independent formation.

The problem of the Miocene-Oligocene boundary also is considered. It is noted that this boundary is very distinct in marine deposits; in continental deposits, on the other hand, its determination is difficult because Miocene and Oligocene floras are fairly similar. Here, the boundary is drawn tentatively on the base of thick sand spreading over the entire area of distribution of the Lower Rhine brown coal formation.

Tectonically, the Lower Rhine Bay area is divided into two parts — the western, which underwent a comparatively rapid Tertiary subsidence; and the eastern, which remained more quiescent. Such a differentiation is based on the geologic structure of the area and is corroborated by gravity curves.

It is pointed out that the splitting of the Main coal horizon in the west is related to the more rapid sinking there of the peat accumulation area. As a result, the Main

coal horizon is discrete in the east, attaining 90 meters in thickness; in the west it is broken up by fairly thick rocks with a marine fauna. The individual beds are (reading upward): Morken, Frimmersdorf, and Hartzweller. The author also believes that the difference in the rate of sinking has resulted in the formation of Oligocene and Miocene sediments in the west, while only the Oligocene is present in the east. Data on the tectonic development in the Lower Rhine Bay area are illustrated by cross sections. It is pointed out that a tropical climate with a mean annual temperature of 21° C prevailed in Early and Middle Oligocene, in the time of coal formation. Subtropical climate, with an 18° C mean temperature prevailed in Late Oligocene and Early and Middle Miocene. The Late Miocene marked the advent of a cooler climate, with temperatures dropping to 15° C.

A picture of the paleogeographic development of the Lower Rhine Bay formation is drawn on the basis of the sediment distribution. It is marked by a definite distribution of marine, deltaic, and marsh facies over this area, from Lower Oligocene to Upper Miocene.

It is emphasized that the formation of the unusually great thickness of the Main coal horizon (up to 90 meters) was due to a combination of different factors, such as paleogeographic (location of a peat accumulation area in the central part of the Lower Rhine Bay trough), tectonic (a relatively long sinking), and climatic (a humid climate, temporarily becoming relatively arid).

As stated before, this review cannot go into details of the numerous papers in the book. The latter contain many new and interesting material, and undoubtedly should attract attention of students of the Tertiary, coal geologists, coal petrographers, paleobotanists, and paleontologists.

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CHRONICLE

REVIEW OF SCIENTIFIC RESEARCH WORK ON ABSOLUTE AGE DETERMINATION OF ROCKS AND MINERALS IN THE U. S. S. R.¹

by

T. B. Pekarskaya

Radioactive determination of the age of rocks and minerals, initiated in this country in 1924, has great theoretical and practical value. Academician V. I. Vernadskiy was one of the first to appreciate it. He defined radiogeology as "a study of the course of radioactive processes on our planet and their reflection and manifestation in geologic phenomena."

According to him, the main task of radiogeology is to establish absolute chronology of geologic events as determined by the processes of radioactive decay of lead and helium, in quantities which are a function of time. He outlined two kinds of determination: one, of the duration of geologic events, and the other of the age of geologic strata. Firmly convinced as to the value of absolute dating, V. I. Vernadskiy organized the work in this field at the Radium Institute, Academy of Sciences, U. S. S. R., where first age figures for geologic formations of the U. S. S. R. were obtained under the direction of Academician V. G. Khlopin.

Among the results of the work of V. G. Khlopin and his school, along with a systematic determination of absolute age for rocks and minerals from various regions of the Soviet Union, were a number of original methods; of fundamental importance was the xenon method (xenon is a product of spontaneous fission of U^{235}).

First determinations of the age of min-

erals were performed in 1925 on uranite from north Karelian pegmatites by K. A. Nenadkevich, who used the lead method, and by V. G. Khlopin, who used the helium method. The V. G. Khlopin determinations resulted in much lower values.

Later, in 1931, this work was resumed by the All-Union Geological Institute (VSEGEI), in the I. Ye. Starik laboratory. I. Ye. Starik and his collaborators (N. M. Segal, O. S. Melikova, A. S. Starik, and Vereshchagin) developed techniques of the lead method: 1) for the determination of small amounts of lead: a) a method of radioactive control of its liberation by percent, b) a method of isolating the lead and its subsequent polarographic determination (1932); 2) for a polarographic determination of uranium (1936) and of the transfer into solution of radium and thorium from minerals of any composition, with their subsequent emanation determination (1930). Of importance also was the determination of their emanation capacity and of the leaching of individual elements from them, as a criterion of fitness of these mineral samples in the age determination work.

In 1932, I. Ye. Starik demonstrated on khlopinite that the niobium-tantalum-titanium group minerals may be suitable for age determination by the helium method; that was the beginning of development of the helium method. Results of the application of this method were reported at the 1932 Session of the International Geological Congress in Washington.

All of these techniques of the lead and helium methods of rock age determinations are in use now, practically unchanged. However, the development of a mass spectrometric method of isotope lead determination was begun in later years, for the common lead content of minerals. It also should be noted that I. B. Borovskiy, of the Institute of Geologic Sciences at the U. S. S. R. Academy of Sciences, proposed in 1947 an x-ray spectrographic determination of the ratio of

¹Obzor nauchno-issledovatel'skikh rabot po opredeleniyu absol'yutnogo vozrasta gornykh porod i mineralov v SSSR.

uranium, thorium, and lead, instead of their absolute values. An advantage of this method is the small amount of rock material (10 to 50 milligrams) necessary for analysis; the X-ray spectrographic method, however, is suitable only for a rapid obtaining of preliminary data, because it leaves undetermined the isotope composition of the isolated lead. In the future, the two methods should be combined.

The helium method was developed in the Radium Institute, by V.G. Khlopin and his co-workers. Of foremost importance in this field is the work of V.G. Khlopin, E.K. Gerling, and E.M. Ioffe on a detailed study of helium emanation from minerals during heating; the dual nature of this emanation has been thus established. In his later work, E.K. Gerling has shown that helium is present in minerals in two states, and its emanation is related to definite values of the diffusion heat. These values, obtained by E.K. Gerling for various minerals, he accepted as a basis for evaluating the fitness of individual minerals for age determination.

Later on, E.K. Gerling proposed to determine the age of minerals with a dense crystalline packing, for he believed that losses would be small under such conditions. However, I. Ye. Starik, G.A. Murina, and A. Ya. Krylov have shown by additional study of a number of garnet samples that crystalline packing alone is not an adequate criterion of fitness of mineral samples and that the form of occurrence of mother materials (uranium and thorium) in a mineral crystal is of substantial importance, as is the state of preservation of the sample.

In 1947, V.G. Khlopin and E.K. Gerling began developing the argon method for determining geologic age. After numerous age determinations by this method, E.K. Gerling and associates have established that the age values so obtained are in fair agreement with those determined by the lead method.

Later on, a rapid method for the age determination of geologic formations, by radioactive decay of K^{40} to Ar^{40} was developed in the Dagestan Affiliate of the U.S.S.R. Academy of Sciences.

The rubidium-strontium and the carbon methods have not yet been widely applied in the U.S.S.R. Only very recently a luminescent installation was set up for determining C^{14} (Radium Institute of the U.S.S.R. Academy of Sciences in conjunction with the Leningrad Section of the Institute of Material Culture), as well as a special installation in the Institute of Geochemistry and Analytic Chemistry at the Academy. This method is being developed in Laboratory of Precambrian Geology, Institute of Geologic Sciences, and

Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, of the U.S.S.R. Academy of Sciences

The main reason for the erroneous age data obtained by radioactive methods is the poor state of preservation of a sample, because of secondary processes taking place under natural conditions, such as the migration of radioelements and their different degree of leaching and emanation. As a result, the radioactive equilibrium is disturbed and the age determination of such samples is obviously impossible. Accordingly, it becomes essential to set up criteria for the fitness of samples for this purpose. Appropriate study is under way in the Radium and the Geochemistry and Analytic Chemistry Institutes of the Academy and in the Kazakh State University (V.V. Cherdyn-tsev).

In 1936, I. Ye. Starik, working at the Radium Institute, proposed a method for determining the age of the Earth's crust from the Pb^{206} and Pb^{207} isotope ratio; he also calculated this age from F. Aston's data on the isotope content of common lead. In 1952, new experimental data on the isotope content of lead ores were obtained by Academician A.P. Vinogradov, at the Institute of Geochemistry and Analytic Chemistry. These data provided a basis for new calculations of the age of the earth. The results so obtained were in full agreement with the earlier results. Work on the age determination of younger formation is being carried on chiefly in the Radium Institute and the Kazakh University (V.V. Cherdyn-tsev).

A scale of absolute geologic age for minerals and rocks was worked out a little over 40 years ago, and has become popularly used in geology. It lists the absolute ages for earlier biostratigraphic subdivisions. It was constructed from foreign radiochemical determinations of rocks and minerals collected from various formations abroad.

The main shortcoming of that scale was the extremely limited number of points on which it was based and the controversial nature of some of the geologic assumptions it implied. The current task is to check that scale, both in terms of quality of the analyses and their computation in the light of modern concepts of radioactive decay, and in terms of stratigraphic position and state of preservation of the material analysed. It is essential to obtain sufficiently reliable numerical data from the Asian continent which was not taken into consideration in the early scale.

In recent years, the work of determining the absolute age of rocks has become particularly

intensive in Institutes of the U.S.S.R. Academy of Sciences, in the Academies of the Union Republics, in some Affiliates of the U.S.S.R. Academy, and in industrial scientific research institutes.

Because paleontologic methods are inapplicable in differentiating Precambrian formations, priority is given to the age determination of such formations in the Baltic and Ukrainian crystalline shields; then to the Caucasus, Urals, Kazakhstan, Trans-Baykalya Far East, etc.

At the present time, systematic work on the absolute age determination of geologic information is being carried on in the following institutes of the U.S.S.R. Academy of Sciences: the V. G. Khlopin Radium Institute; the V. I. Vernadskiy Institute of Geochemistry and Analytic Chemistry; Laboratory of Precambrian Geology: IGEM; the Dagestan, Bashkirian, Uralian, and West Siberian Affiliates; also at the Ukrainian, Georgian, Armenian, Kazakh, and Azerbaydzhan Academies; the All-Union Geological Institute; the Kazakh Section of the VIMS; the Leningrad and Moscow State Universities; and the Kazakh State University.

A number of original radioactive methods were first developed in the Soviet Union along with the first studies on the behavior of individual radioelements in natural objects—the latter study essential for understanding the results—and with an evaluation of errors in the determinations by radioactive methods.

Despite the fruitful development of this work, it is hampered by the lack of proper liaison between geologists and radiologists and by insufficiently active participation by radiologists in the geochronologic study of rocks and minerals. The success of a Soviet geologic age scale depends chiefly on the properly organized cooperation of radiologists and geologists, as demonstrated by their joint efforts in differentiating Precambrian rocks of the Ukraine and Karelia (A. A. Polkanov, N. P. Semenenko, A. P. Vinogradov, L. M. Komlev, and others) and the Caucasus (G. D. Afanas'yev and others). Their work has already produced tangible results. Voluminous material has been gathered on the absolute age of Paleozoic and Mesozoic intrusions and on Precambrian deposits in the Baltic and Ukrainian shields.

Interesting methodologic studies have been carried out recently in the Soviet Union, specifically on the feasibility of application of radioactive methods on the age determination of sedimentary rocks. Satisfactory results have been obtained on glauconite in the VSEGEI and the Dagestan Affiliate of the Academy (by

N. I. Polevaya, G. A. Kazakov, Kh. I. Amir-khanov, and S. B. Brandt). Glauconite as a mineral suitable for age determination was first suggested by M. M. Rubinshteyn, in 1955. Of interest is the experiment in the age determination of the source material of sandstone and shale, which is very essential for paleogeographic reconstructions (A. Ya. Krylov, Yu. I. Silin, the I. Ye. Starik Laboratory).

The most recent work includes a study of the migration capacity of potassium and argon (E. K. Gerling, I. M. Morozova, S. B. Brandt, Ye. N. Barnitskiy), a development of the "calcium" (N. I. Polevaya, N. Ye. Titov, Ye. D. Sprintson), the "rhenium" (I. Ye. Starik, V. M. Aleksandruk), and the x-ray (A. S. Serdyukova, Yu. T. Kapitanov) methods, as well as the pyrochemical method based on quantitative liberation of lead from minerals, rocks, and meteorites, which guarantees the isotopic purity of lead preparations so isolated (I. Ye. Starik, E. V. Sobotovich, G. P. Lovtsyus).

All this work is carried out on a single plan, under the direction of the Commission for the Determination of Absolute Age of Geologic Formations, at the Geologic and Geographic Sciences Section, Academy of Sciences, U.S.S.R. (Corresponding Member I. Ye. Starik, Chairman; Academician D. I. Shcherbakov and Professor V. I. Baranov, Acting Chairmen; Candidate in Geological and Mineralogical Sciences T. B. Pekarskaya, Academic Secretary; members: Academicians N. S. Shatskiy, A. A. Polkanov, A. P. Vinogradov; N. P. Semenenko, of the Ukr. S. S. R. Academy of Sciences; Corresponding Members of the U.S.S.R. Academy, G. D. Afanas'yev and V. V. Belousov; Professors E. K. Gerling, A. A. Bogdanov, R. F. Gekker; Candidate in Geological and Mineralogical Sciences A. I. Tugarinov, and Junior Scientist S. I. Zykov).

The Commission is carrying on extensive scientific and organizational work; it was initiated in 1950, together with the first planned work on absolute age determination in the Soviet Union.

The work of this Commission consists of annual sessions which summarize the preceding year's results.

It appears from this review that radioactive methods are beginning to become deeply rooted in geologic practice; there is every reason to believe that the next few years will witness the first tentative Soviet geochronologic scale of absolute age.

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METALLOGENIC CONFERENCE IN NOVOSIBIRSK²

by

G.F. Yakovlev

The coordination of the work of numerous geologic organizations carrying on the study

of regular patterns in the distribution of minerals, particularly in Siberia, is a very important task.

In this connection, and at the initiative of Institute of Geology and Geophysics at the Siberian Affiliate of the U.S.S.R. Academy of Sciences and the Siberian Scientific Research Institute of Geology, Geophysics, and Minerals Resources of the Ministry of Geology and Mineral Conservation of the U.S.S.R., an interdepartmental conference on metallogeny of the Altay-Sayan fold province took place in Novosibirsk, April 25 to 27, 1959. Geologists from the All-Union Geological Institute (VSEGEI), the West Siberian, Krasnoyarsk, and Novosibirsk Geologic Administrations, the Glavgeologii Expedition of the R.S.F.S.R., and the Krasnoyarsk Sovnarkhoz were among the participants.

Among the speakers were Academician A.A. Trofimuk (on the main problems of regular patterns in distribution of minerals, facing the Siberian geologists), Corresponding Member V.A. Kuznetsov ("Some General Principles of Metallogenic Analysis of Fold Provinces, and the Present Status of the Problem" and a communication on the 1959 to 1965 work schedule in the Institute of Geology and Geophysics at the Siberian Section of the U.S.S.R. Academy of Sciences, on endogenetic metallogeny in the Altay-Sayan fold province), and V.P. Kazarinov (a communication on the 1959 to 1965 schedule for the Siberian Scientific Research Institute of Geology, Geophysics, and Mineral Resources [SNIIGGIMS], on exogenetic metallogeny). In addition, informative communications on the 1959 to 1965 schedules on Altay-Sayan metallogeny were read by the representatives of all the above-mentioned organizations.

The conference resolved that metallogenic study by the several organizations be conducted on a single plan, actively administered by a territorial interdepartmental commission; such a commission, counting 24 Siberian geologists, was elected (Corresponding Member of the U.S.S.R. Academy of Sciences V.A. Kuznetsov, Chairman).

Two stages of metallogenic work were outlined:

1) 1959 to 1961. Compilation of index and preliminary exploration maps for principal ore minerals, to direct the prospecting work during the Seven Year Plan. Present 1:500,000 geologic maps are to be used as base maps.

2) 1962 to 1965. Working out various problems of Altay-Sayan metallogeny for the compilation of 1:500,000 to 1:1,000,000 and 1:200,000 exploration maps for principal ore

²O metallogenicheskom soveshchani v g. Novosibirsk.

and non-ore minerals (Iron, manganese, titanium, chromium, nickel, mercury, gold, non-ferrous and rare metals, asbestos, talc, etc.); all culminated in a comprehensive metallogenic map and a monograph, "Metallogeny of the Altay-Sayan Fold Province." Separate preliminary stages of this work were designated as follows:

1) a composite specialized geologic map, 1:500,000 to 1,000,000, with a geologic legend;

2) a structural scheme of differentiation and a 1:500,000 to 1,000,000 tectonic map with a tectonic outline;

3) a summary of igneous activity;

4) geophysical maps;

5) lithologic facies maps of principal stratigraphic subdivisions;

6) index map for all kinds of ores and their showings;

7) consumption maps of mineral resources with elements of geologic and economic differentiation.

A subcommission was appointed to carry out the first stage; the work of the second stage sections was distributed among the members of the commission.

The above-named tasks are being carried on by the Siberian Scientific Institute of Geology, Geophysics, and Mineral Resources; by the Institute of Geology and Geophysics of the Siberian Section of the U. S. S. R. Academy of Sciences; the All-Union Geological Institute; and the All-Union Aero-Geological Trust — all with the participation of local geologic administrations.

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